Environmental Effects
Overview

OCS Report
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Marine Mining on the Outer Continental Shelf

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Minerals Management Service

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Abbreviations

°C	degree Celsius (centigrade)
cm	centimeter
cm^2	square centimeter
ft	foot
ft^2	square foot
g	gram
in	inch
kg	kilogram
km	kilometer
km^2	square kilometer
lb	pound
m	meter
m^2	square meter
mg	milligram
mi	statute mile
mi^2	square statute mile
mm	millimeter
nm	nautical mile

Acronyms

ATOS	Anti-Turbidity Overflow System
DOI	Department of the Interior
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
HI	Hawaii, State of
MMS	Minerals Management Service
NAS	National Academy of Science
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
OCS	Outer Continental Shelf
OTA	Office of Technology Assessment
SI	International System of Units (metric)
U.S.	United States
USGS	U.S. Geological Survey

1. Introduction

This document is an overview of the ways in which mining may be carried out under regulations being established by the Minerals Management Service (MMS) of the Department of the Interior (DOI). The objective is to provide the reader with a sense of what is, and what is not, known about the environmental effects of mining on the Outer Continental Shelf (OCS). As the difference between the Exclusive Economic Zone (EEZ) and the OCS is strictly legal, similar environmental effects would apply to marine mining on any parts of the EEZ which may not be in the OCS.

Detailed analyses of specific areal environmental impacts of OCS mining will be presented in Environmental Impact Statements (EIS) as specific target areas and commodities are considered for leasing, exploration, and development. This document generally describes potential mining activities on the OCS and their effects. Neither activities in waters under State jurisdication nor minor exploration activities are specifically discussed.

Section 2 highlights the diverse mineral deposits and environmental settings of the OCS. Section 3 describes the mining methods that now appear most applicable to OCS mining and gives references to supporting literature. Section 4 discusses how these mining methods would disturb the environment during the course of normal operation. Section 5 summarizes the concerns raised by a literature search into the known environmental impacts of OCS mining disturbances. Conclusions based on current knowledge of the environmental impacts that may follow the establishment of OCS mining regulations are presented in Section 6. Section 7 describes MMS's policy to comply with the National Environmental Policy Act (NEPA) and provide for State, local, and public input, as well as resource development.

Measurements in Section 3 are reported in U.S. customary (English) units to conform to usual practice in the U.S. mining industry. Other measurements throughout the report are given in SI (International System of Units) metric units in accordance with standard practice in geology and biology. An English-metric conversion table is presented in Appendix 1.

2. Diverse character of the Outer Continental Shelf

2.1. Mineral deposits

Mineral deposits on the OCS can be characterized either as unconsolidated, capable of being collected directly by dredging; or consolidated, requiring additional energy to fragment the deposit before collection (Cruickshank, 1962; table 1). Either type may occur at or beneath the seafloor.

Unconsolidated deposits include construction materials such as sand, gravel, and shells; heavy mineral placers, containing materials such as titanium, tin, and gold; metalliferous muds such as those under development in the Red Sea; and nodules and oozes of silica and calcium carbonate.

Consolidated deposits include bedded deposits, such as coal and iron ore; crusts, such as the cobalt-rich manganese oxides found on Pacific Ocean seamounts; massive sulfide deposits in the form of mounds and stacks occurring at certain spreading centers; and essentially tabular veins or mineralized channels in consolidated host rocks.

Fluids may be considered special cases. They are represented by dissolved salts traditionally recovered by evaporation ponds; slurries of fine-grained, loosely consolidated materials; and hydrothermal solutions of materials.

Most of the known U.S. deposits that could be economically mined are comprised of unconsolidated or weakly consolidated materials. Possible exceptions are the consolidated, cobalt-rich, ferromanganese crusts and polymetallic sulfides being considered for leasing now. Consolidated deposits of phosphorite may also be of interest in the future, but potential markets exist now for unconsolidated deposits of sand and gravel and heavy mineral placers (Bureau of Mines, 1987a and 1987b).

It is assumed that most economically recoverable deposits are found on the continental shelves at depths of 200 m or less. Individual mines are expected to cover between 3 and 40 mi^2 (about 8-100 km^2) or less than 0.01 percent of the roughly 400,000 mi^2 (about 1,000,000 km^2) of continental shelf. Mines would last 20 years or more. The most extensive operations in U.S. waters probably would involve manganese crust mining. Such a mine could require 500-600 km^2 for a 20-year operation. However, one such mine could provide half the nation's demand for cobalt and substantial amounts of other strategic metals.

Table 1 Classification of marine mineral resources

Fluid		Unconsolidated		Consolidated	
Seabed	Subseabed	Seabed	Subseabed	Seabed	Subseabed
Seawater Magnesium Sodium Uranium Bromine & Salts of 26 other elements	Hydrothermal fluids	Industrial Materials Sand & gravel Shells Aragonite Heavy Mineral Placers Magnetite Ilmenite, Rutile Chromite, Monazite Nodules Manganese Phosphorite Muds and oozes Metalliferous Carbonaceous Siliceous Calcareous Barite	Heavy Mineral Placers Gold Platinum Cassiterite Gem stones Bedded Deposits Phosphorites	Crusts Phosphorite Cobalt Manganese Mounds and Stacks Metallic sulfides	Disseminated, Stratified, Vein, or Massive Deposits Coal Phosphates Carbonates Potash Ironstone Limestone Metallic sulfides Metallic salts

2.2. Environmental settings

The submerged lands of the U.S. EEZ, established by President Reagan's proclamation of March 10, 1983 (Procl. 5030, 3 CFR 22), are large and varied. They cover about 4.2 million mi^2 (about 11 million km^2), an area 30 percent larger than the land area of the United States (figure 1). About 15 percent of this area lies on the geologic continental shelf and is shallower than 200 m. Another 10 to 15 percent consists of the continental slope and rise, lying between 200 and 4000 m. The remaining 70 to 75 percent are abyssal plains at depths of 3 to 5 km.

The EEZ generally consists of those areas within 200 nm of the coast of the United States and its territories and possessions, subject to adjustment with conflicting claims of adjacent and opposite nations. Most of the EEZ is under Federal jurisdictions, but the tidal and submerged lands within 3 nm of shore are under State (and in some cases, territorial) jurisdiction. In certain areas in the Gulf of Mexico, State jurisdiction extends to 3 marine leagues (9 nm). The OCS includes those portions of the EEZ subject to Federal jurisdiction which are adjacent to the 50 States and, in some regions, extends seaward beyond the EEZ. It should be noted that the legal continental shelf includes submerged lands which are not customarily considered part of the geological continental shelf. When the term "continental shelf" is referred to in this overview, the geological continental shelf is meant.

The physical environments of the OCS are varied, with strong regional variations in water depths, physiography, wind, wave, tidal and current regimes, and biota. Detailed descriptions of these variations on the continental shelf are given in the EIS's prepared for offshore oil and gas lease sales and some of the appendices of the DOI's program feasibility document for OCS hard minerals leasing (DOI, 1979). The EIS for the proposed lease sale of cobalt-rich manganese crusts (DOI and HI, 1987) and the EIS for manganese nodule mining (NOAA, 1981) describe two pertinent environments off the continental shelf, although the latter involves an area outside of the OCS and EEZ. Descriptions of a third will be published in 1987 by the DOI and the State of Oregon as the proceedings of the Gorda Ridge Symposium. Sections 2.2.1 and 2.2.2 outline variations in the bathymetry, physiography, and biology of the OCS as background to discussions of the environmental effects of OCS mining in Sections 4 and 5.

2.2.1 Regional bathymetry and physiography

Alaska

The continental shelves of northern and western Alaska are notoriously hostile working environments. Ice cover is heavy and mobile much of the year, resulting in deep gouging of the shallower portions of the seafloor, and the seafloor in deeper waters is prone to slumping. The shelf is at least 100 km wide along the northern coast and is bounded to the north by steep scarps that are scarred by slumps and leveed channels. Seaward of the scarps lie abyssal plains at depths of 2.5 to 3 km (Nikituk and Farris, 1986; Collins and Lynch, 1985).

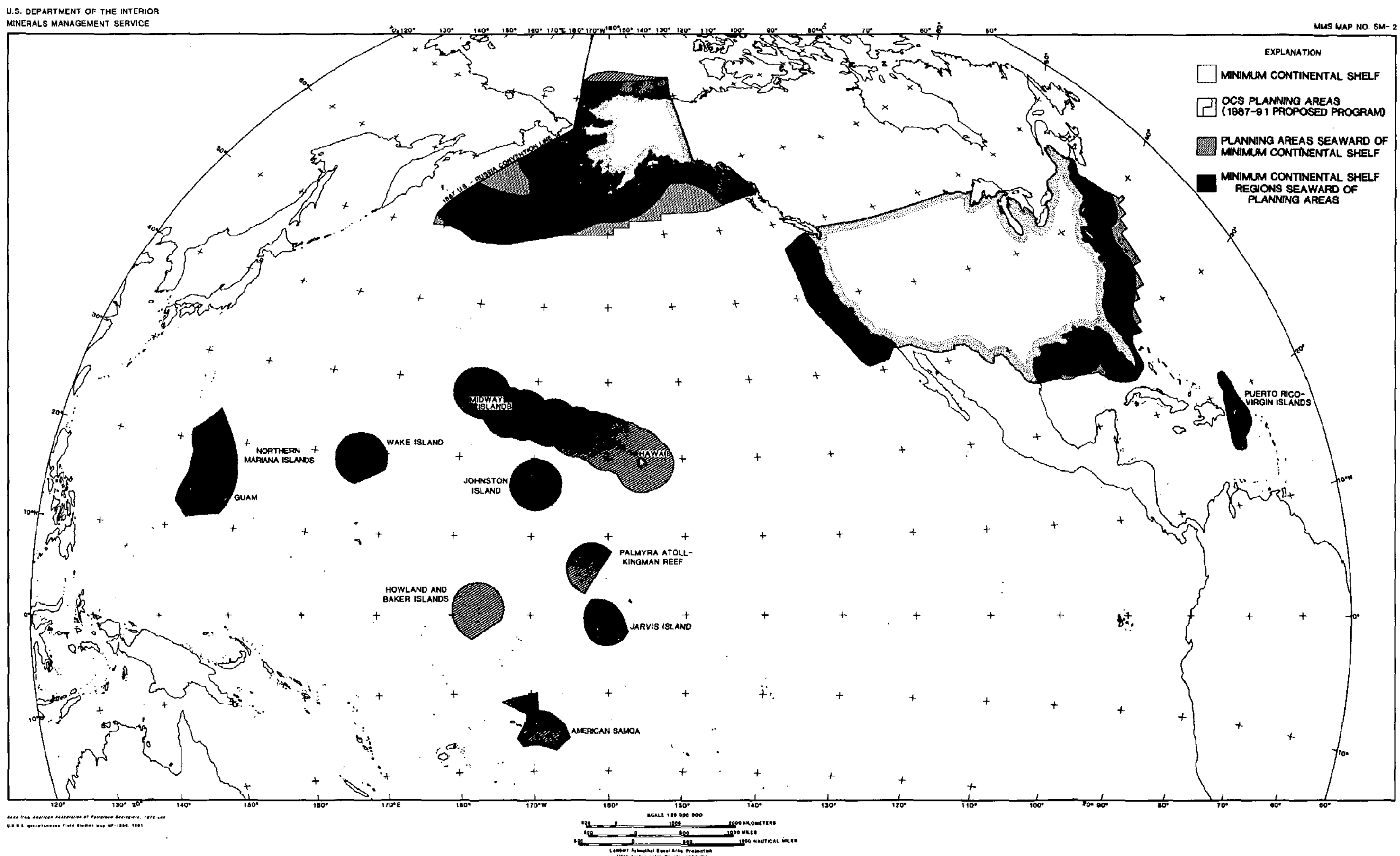


Figure 1 - Exclusive Economic Zone of the United States, Commonwealth of Puerto Rico, Commonwealth of the Northern Mariana Islands, and U.S. territories and possessions.

West of the Alaskan mainland, the shelf is a shallow, gently sloping extension of the coastal plain. Generally shallower than 100 m, it ranges in width from over 830 km in the north to 500 km in the south. With few exceptions the shelf floor is nearly featureless and flat. The average slope is roughly 0.25 m/km (0.025 percent). To the south, this vast plain is bounded by steeper, but still gentle, slopes that are scarred by large canyons (Nikituk and Farris, 1986).

Southwest of the mainland, the Aleutian Islands, the adjacent Aleutian trench, and a major chain of seamounts are the most striking physiographic features. The seafloor in this area is otherwise a sediment covered plain 3-5 km deep, with scattered seamounts. The area is seismically and volcanically active, with activity concentrated along the Aleutian Islands (Nikituk and Farris, 1986).

Pacific Coast

Along the Alaskan panhandle and south along the Washington, Oregon, and northern California coasts, the shelves are very narrow, generally about 25 km wide. The outer edges of these shelves are generally at a water depth of 100-160 m. The slopes bordering these shelves are characterized by extensive slumping and massive canyons. The abyssal plains seaward of these slopes are 2-3 km deep north of the Mendocino Ridge, and 3-4 km deep south of it. The ridge itself is a 500-meter high structure that lies along the seaward extension of the San Andreas fault system. It is bordered to the south by a major enscarpment that extends from Cape Mendocino, California to the outer edge of the OCS (Nikituk and Farris, 1986; Shepherd, 1963).

Just north of the Mendocino ridge, and extending northward along the southern third of the Oregon coast, is the Gorda Ridge, the only fragment of the global system of oceanic spreading centers in the OCS. This ridge has an axial rift valley whose floor lies 0.8-1.4 km below the adjacent ridge crests and 3 km below the sea's surface. Many small seamounts lie along the axial valley although these are often buried by sediments of continental origin in the southern part of the valley (Clague et al., 1984; DOI, 1983a).

Along the southern California coast, rugged, mountainous terrain replaces the typical flat shelf. The crests of several of these mountains form the Channel Islands and shallow offshore banks. The basins between these islands and banks are generally 1 to 2 km deep and are isolated from each other at water depths greater than 500 m (NOS, 1975). The area, like the rest of the Pacific coast, is seismically active.

Atlantic and Gulf Coast

The Atlantic and Gulf coasts show the zonation typical of the Pacific coast; but the zones are broader. The continental shelf in the North Atlantic is 40-330 km wide off the New England coast with water depths of 200 m at the edge of the shelf. The slope of the seafloor then steepens more than tenfold in a zone, known as the continental slope, before ending at depths of 2-3 km in the much gentler slopes known as the continental rise. The continental rise then extends seaward until it terminates in abyssal plains about 5 km below the surface.

The continental shelf of the Mid-Atlantic varies in width from 25 km off Cape Hatteras to 200 km off New York. The shelf slopes at 1 to 2 m/km (0.1 to 0.2 percent), reaching a depth of about 200 m at its seaward edge. The Mid-Atlantic continental slope is steep and narrow, from 20 to 40 km wide, and is cut by many large canyons (Nikituk and Farris, 1986).

The South Atlantic continental margin continues the simple combination of shelf, slope, and rise, except for a broad plateau 0.6 to 1.2 km deep known as the Blake Plateau. This plateau is about 280 km wide offshore northern Florida and tapers gradually both northward and southward. The plateau merges with the continental slope offshore North Carolina to the north, and the Bahamas to the south. The shelf in the South Atlantic is generally 30 to 140 km wide, exclusive of the Blake Plateau (Charles River Associates, 1979; Nikituk and Farris, 1985). The average slope of the continental shelf is less than 3 m/km (0.3 percent) in the South Atlantic. Water depths at the edge of the shelf generally average 50-90 m (Nikituk and Farris, 1986).

The geologic shelves of the Central and Western Gulf are generally 100-200 km wide. The continental slope then extends another 250 km into the Gulf and lies between 100 and 3000 m deep. Geohazards include mass slumping, sediment creep, and landslides on the slope, particularly near the mouths of the Mississippi River (Nikituk and Farris, 1986).

Carribean and Pacific Basins

The Caribbean and the Central and Western Pacific portions of the OCS and EEZ consist primarily of abyssal plains with scattered, steep-sided, submarine volcanoes or chains of volcanic islands such as the Hawaiian Archipelago. The principal exceptions are the island arcs of the Antilles in the Caribbean and the Mariannas in the Western Pacific. These areas are adjacent to deep, narrow, oceanic trenches. The oceanic islands, whether scattered or in chains, have narrow, shallow shelves comprised of living and dead corals and steep, submerged slopes. For example, water depths north of Puerto Rico are less than 20 m within 1 kilometer of shore shore, but 200 m deep within the next kilometer. The platform is about 5 km wide to the south, and 10-20 km wide to the northeast and southwest. Ocean depths reach 7.5 km north of the island, and over 5 km to the south (NOS, 1984). The nearshore bathymetry around other oceanic islands in the OCS and EEZ is similar (Shepherd, 1963).

2.2.2 Biology

For the purposes of this overview, the most important biological variations in the OCS are associated with feeding habits, life cycles, mobility, and adaptation to physical disturbances. Biological impacts are summarized below; further details are provided in Section 5.

Typically, species that inhabit areas subject to frequent physical disturbance tolerate heavy sedimentation. Generally, these environments have few species, but many individuals of each of those species. In contrast, species living in environments with low sedimentation rates often are quite sensitive to turbidity and moderate to heavy sedimentation. These environments frequently have many species, but most are represented by only a few individuals at any given site. However, these species may be widely dispersed geographically.

The fishes of coastal and upper oceanic waters should be able to readily avoid mining disturbances as adults, but may be unable to do so during the egg and larval stages, when they are attached to the bottom or passively floating. If so, their highest exposure to injury from mining would occur at ages when the natural death rates are highest. Injuries to these species caused by mining would be hard to detect, except in laboratory tests. This would be especially true of effects which are not themselves lethal, even though they may make the animal more susceptible to other hazards, such as predators. These so-called sublethal effects need continued study, since end points other than death and disappearance are not well understood (OTA, 1987). Species that are territorial as adults, or that occupy rare habitats are effectively immobile even if they are physiologically capable of avoiding disturbances. Such species would be subject to adverse impacts as both juveniles and adults.

These generalizations concerning the life histories and behaviors of fish are also true of invertebrates, but there may be major differences in scale and sensitivity to mining. Many invertebrates are smaller, more numerous, shorter lived, and reproduce more rapidly than fish living in the same habitat. These attributes facilitate rapid population growth and rapid recovery of the impacted populations. However, many invertebrates are attached to the seafloor for parts of their life cycle; are slow-moving, burrowing, or floating species; or are highly territorial; and hence unlikely to evade mining activities. The result of these opposing sets of attributes probably will be a higher death rate, but more rapid reproductive replacement in invertebrate than in vertebrate populations on a mine site. Both groups, however, will likely recolonize abandoned mines relatively quickly by migration from undisturbed areas.

Lists of the more important species in the various environments of the OCS, and pertinent details of their life cycles and traits, can be found in standard biology texts and in the EIS's prepared by the MMS for oil and gas lease sales in the OCS. Similar accounts of species in the Central Pacific are given in the EIS for the MMS's proposed lease sale for cobalt-rich manganese crusts (DOI and HI, 1987). Accounts of one portion of the deep sea that are typical of what is known are given by the EIS prepared for manganese nodule mining of the deep seabed (NOAA, 1981).

Previously unknown species are regularly encountered in bottom samples from the deep sea, and up to 80 percent of the animals obtained from the deep sea have never been seen before (OTA, 1987). However, while we understand shallow water communities and their responses to disturbances better than deep water communities because we have studied the shallow water organisms longer, the benthic fauna becomes increasingly more uniform horizontally as water depth increases. That is, the composition of the benthic community changes more rapidly with small changes in depth than with large horizontal changes as water depth increases. As a result, shallow or estuarine communities can be quite different from shelf communities, and shelf communities from slope communities (Sanders and Hessler, 1969; Boesch, 1972). However, what we learn at one area in the deep sea will give us more predictive power than would one area in shallow water (Sanders and Hessler, 1969; OTA, 1987).

In general, the biomass of bottom dwelling organisms decreases with depth, but there are local exceptions, such as the great masses of giant worms and clams found near hydrothermal vents and some deep water hydrocarbon seeps (Paull et. al., 1984; Grassle, 1985; Southward, 1985). These communities are thought to develop far more rapidly than the typical deep sea assemblages which receive much lower quantities of food (Grassle, 1985).

The two deep sea areas proposed thus far for leasing in the EEZ fit the general pattern of low biomass. Extensive photo and video coverage of the cobalt-rich manganese crusts show an extremely sparse fauna. Preliminary analysis of photographs seem to indicate a somewhat more abundant than normal biota on or near the sulfide mineral deposits on the Gorda Ridge but the abundance is far short of that typical of vent communities and the species present seem to be those found throughout the region.

There are four basic methods of mining solid minerals: scraping the surface, excavating a pit or trench, removal through a borehole in the form of a slurry or fluid, and tunneling into the deposit (figure 2). All deposits on land are mined by one or more adaptations of these methods and OCS mining is amenable to the same basic approaches (table 2). Each mining method has variations that may be tailored to a specific situation, and most of the deposit types can be mined by more than one method. Similarly any one method can be applied to more than one deposit type (Cruickshank, 1978).

OCS mineral deposits, whether consolidated or unconsolidated, may occur at or beneath the seabed. Deposits at or near the surface of the seabed can be gathered by mechanical devices that scrape the seabed and gather the ore for lifting to the surface or for other treatment. In its simplest form, the action is like raking or shoveling or, in some cases, vacuum cleaning. Where a thick layer of hard material is present, the scraping action may be preceded by ripping or cutting. Mineral deposits lying wholly or partially beneath the sea-floor may be removed by excavation. The applicable mining methods range from those designed to recover free-flowing materials to those for excavating solid rock. Certain types of deposits of solid rock may be mined by borehole methods, whereby fluid is added and ore is transformed into a fluid or slurry and removed by pumping. In some cases, a mineral may be selectively leached and recovered in solution. In other cases, the ore body may be fragmented in such a manner that a slurry of ore is recovered from beneath the seabed. Deposits buried too deeply to mine from the seabed may also be mined by conventional underground mining methods using shafts and adits (tunnels that lead into mines) for access and ventilation, either from shore or from natural or artifical islands. The seabed location of the mines only slightly adds to the conventional problems of access, safe overhead cover, and ventilation. The effect on the environment is much the same as with an onshore mine.

This section further explains each of the mining systems listed on table 2, describes the manner in which each may disturb the marine environment, and notes types of deposits with which it is normally used. For further reading references are provided to literature describing commercial operations using these mining systems (Cruikshank et al., 1968; Cruickshank and Marsden, 1973 and Cruickshank, 1973). To conform to conventional usage in the U.S. mining industry, this section uses U. S. customary (English) units rather than the SI (metric) units used in the rest of the document.

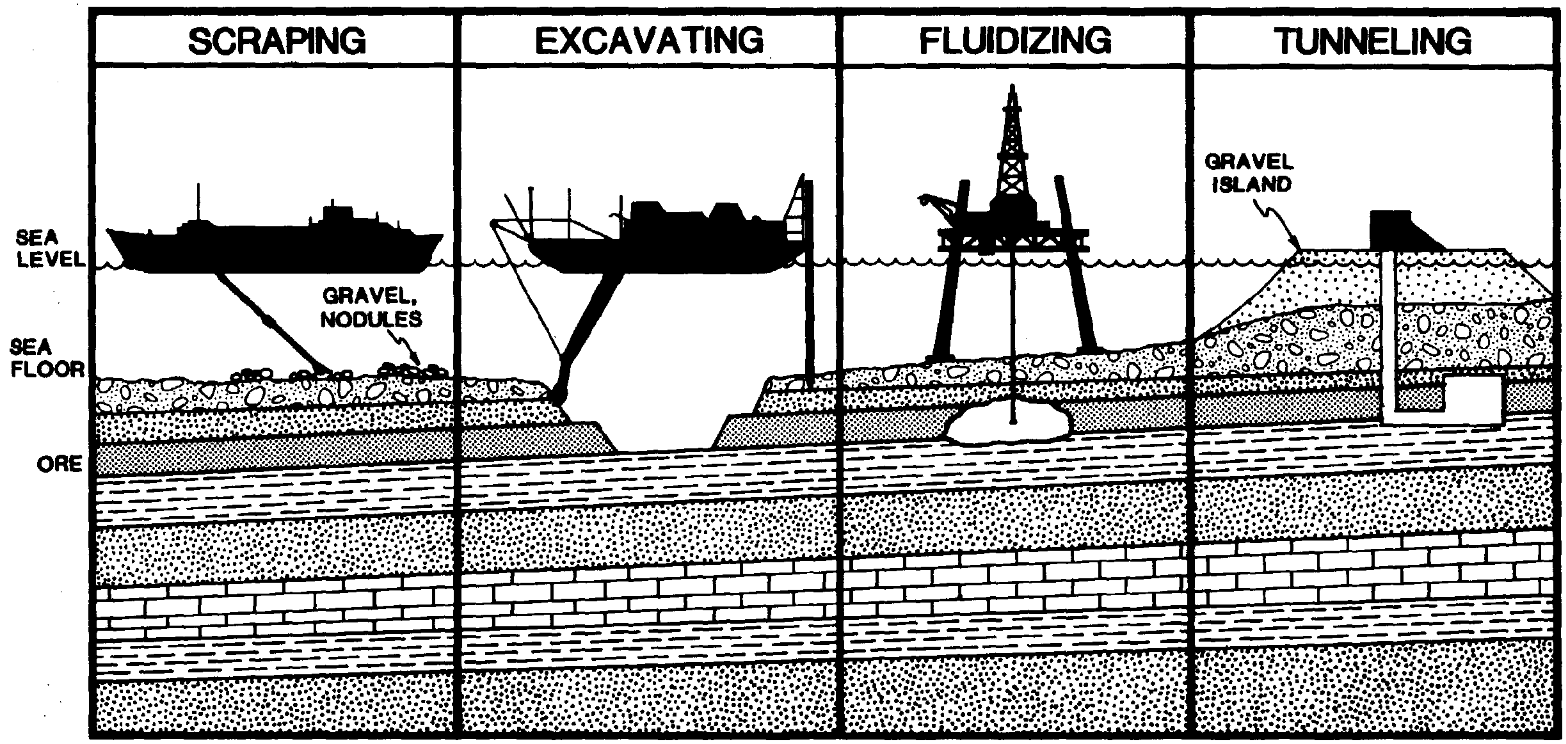


Figure 2 - Basic approaches to mining

Table 2 Mining methods applicable to OCS mineral deposits

Mining Methods		EEZ mineral deposit types (with selected examples)									
		Unconsolidated Deposits					Consolidated Deposits				
Mining Approaches	Mining Systems	Construction Aggregates	Heavy Mineral Placers	Metalliferous Muds	Nodules and Slabs	Oozes	Bedded	Crusts	Massive	Mounds and Stacks	Veins
Scraping	Drag line dredge		A		A						
	Trailing suction dredge	P	A	A	P	F					
	Crust-miner							F			
	Continuous line bucket	F	F	F	A	F		F			
Excavating	Clam shell bucket	A	A						F	F	P
	Bucket ladder dredge	A	P								
	Bucket wheel dredge	A	A								
	Anchored suction dredge	A	A	A		F			F	F	
	Cutterhead suction dredge		P					A			
	Drilling and blasting								F	F	P
Fluidizing (Sub-Seafloor)	Slurrying	A	A	P			F				
	Leaching								F		F
Tunneling Beneath Seafloor	Shore entry						P		A		
	Artificial island entry						A		A		

P= Primary method applicable A= Also applicable F= Future use possible

3.1 Scraping

Although there are many variations, there are basically four mining systems that may be used to scrape the surface of the seafloor. Two are wholly mechanical and two involve hydraulic action to lift the mined rock.

3.1.1 Dragline dredge

This system is used in offshore mining and deep seabed sampling, as well as in construction. Its use has been advocated for the recovery of seafloor nodules and slabs of phosphorites (Mero, 1965). The material would be recovered by large dredge buckets that scrape slabs and nodules from the surface of the deposit and feed them into barges for transportation to shore (figure 3). Annual production at such an OCS mine for phosphorite could be on the order of 400,000 tons (roughly 180,000 yd^3 of ore). This rate of production could involve 50 yd^3 buckets scraping an average of 20 tons of phosphorite from the seafloor every 20 minutes in a water depth of about 600 feet.

At an average abundance of 20 lb/ft, nearly 2 mi^2 of seafloor would be mined annually. At a mine life of 20 years, a total of 40 mi^2 would be affected if the deposits were confined to the surface of the seabed. Thicker deposits would allow smaller areas of disturbance.

Assuming the presence of some fine-grained sediment on the seafloor, as well as some breaking up of the phosphorite, a benthic turbidity plume would be created by the scraping action. Some fine material would inadvertently be introduced into the dredge buckets and washed out either in route to the surface or at the surface as a result of washing of the phosphorite in the barge. The fine sediments would eventually rain to the seafloor, creating a blanket of fines.

3.1.2 Trailing suction dredge

A suction hopper dredge uses a pump to draw a slurry of bottom water and seafloor sediment into a riser or pipe leading to the mining vessel. As the sediment accumulates in the hopper, the water weirs overboard. This system is used primarily for maintaining harbor channels. However, it is also used extensively for mining sand and gravel in water depths up to 120 ft in the North and Baltic Seas (Padan, 1983). New vessels, such as the ARCO Avon, launched in 1986, are designed to extend mining capability to depths of 150 ft (Drinnan and Bliss, 1986). As its name implies, this type of dredge mines while in motion, creating numerous shallow trenches in the seafloor commonly about 3 ft wide and 1 ft deep (figure 4).

The suction dredge uses one of several types of drag head with a coarse-grid steel framework across the opening of the suction head to prevent large rocks from entering the suction pipe. Coarser particle sizes are screened out and rejected after passing through the pump. Fine materials are washed overboard with the slurry overflow. In some cases, vibrating screens allow part of the sand fraction to be dumped back into the ocean since the ratio of sand to gravel mined may differ from the desired marketable mix.

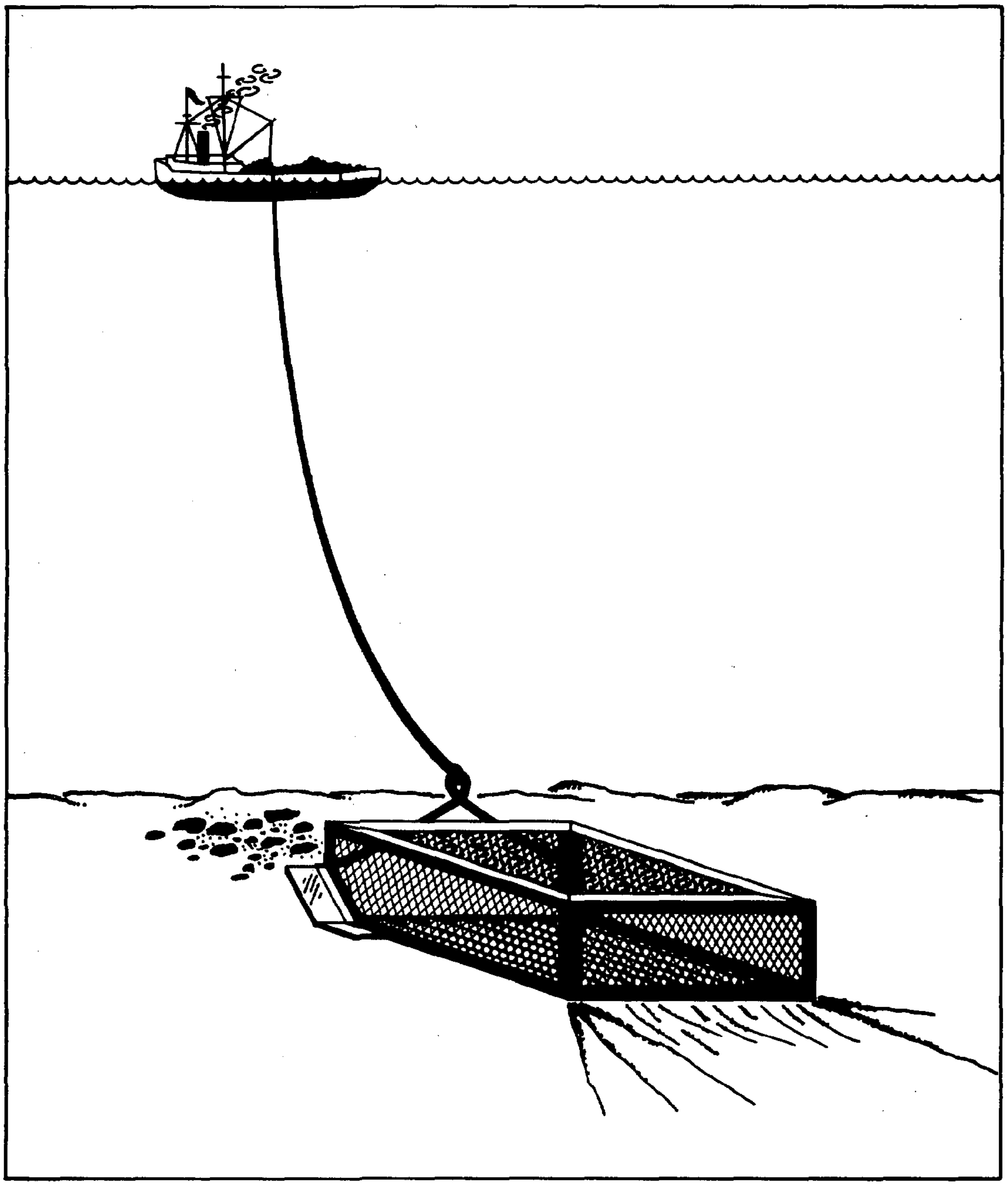


Figure 3 - Drag Line Dredge

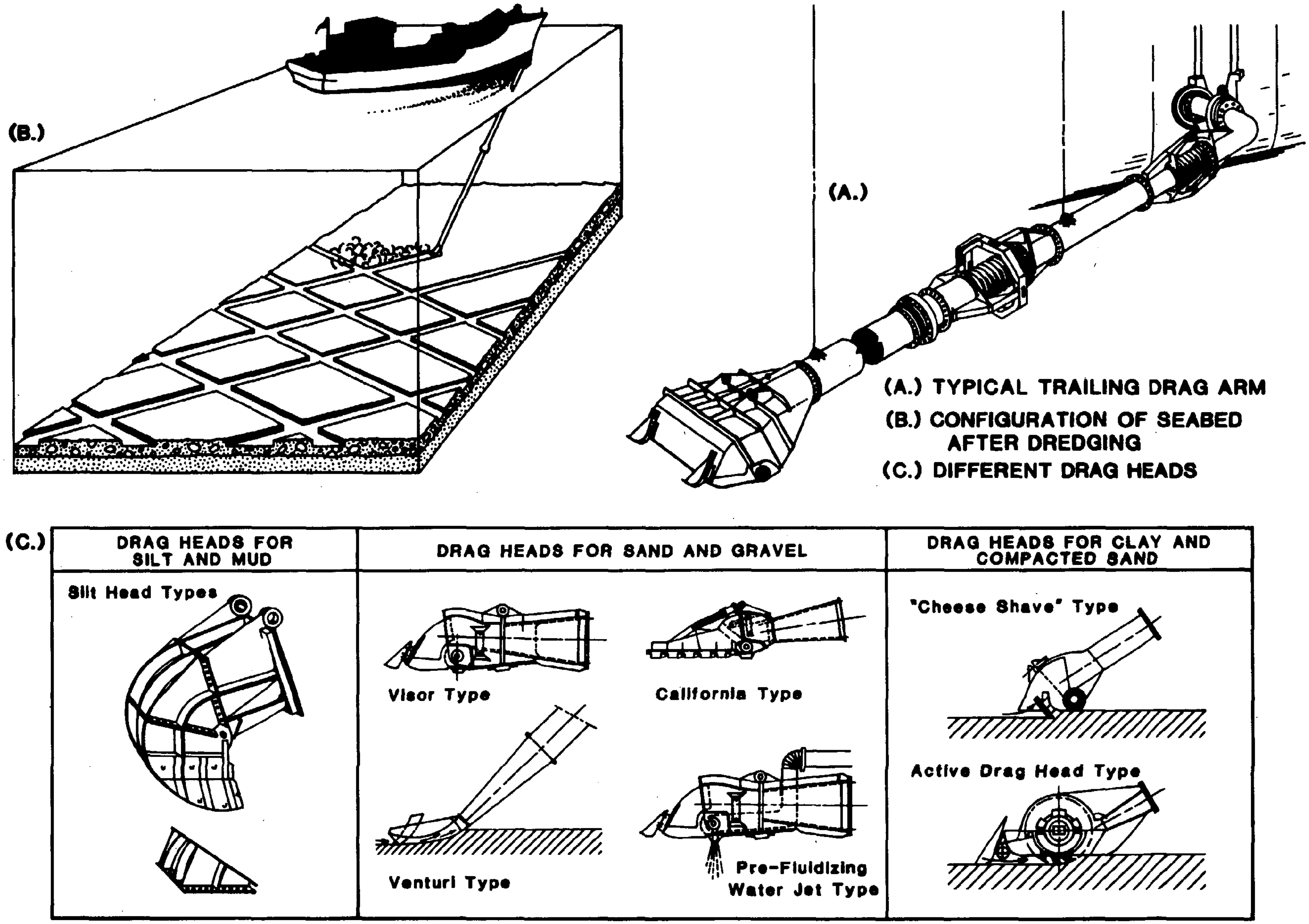


Figure 4 - Trailing suction hopper dredge and representative drag heads

Environmental disturbances that may result from this system include the excavation of trenches in the seafloor, creation of a turbidity plume by washing overboard clay particles taken up in the dredge pipe, and production of a blanket of fines covering the seafloor down current from the dredge. However, measures have been developed in Japan and Great Britain to either avoid or mitigate these problems. The use of sand and gravel as construction material, for example, requires that stringent measures be taken to avoid mining any clay layers since the entire shipload would be considered contaminated and unmarketable. Regulatory options include mandating bottom discharge of overflow waters to reduce the size of surface plumes, and in some cases, bottom discharge of rejected sand to reduce the size of trenches or other excavations. Further details on environmental effects and the technical and administrative means the British have used to control them are given by Drinnan and Bliss (1986) and Pasho (1986). Additional detail on the equipment used and extensive photographic documentation are given by Hess (1971).

The volume of material that may be mined includes the sum of the marketable material, the fraction to be rejected, and the overburden initially stripped away. For example, in moving 1 million tons of product to shore annually, an equal amount of sand might be rejected to reduce the sand/gravel ratio from 70:30 to a more marketable 40:60 (NAS, 1975). The 2 million tons of annual excavation would result in a gradual lowering of the ocean floor by about 2 ft over an area of 1 mi^2 (about 2.1 million yd^3). As mining proceeds, the rejected sand released above the mined out area would partially smooth the bottom contours.

Some silt and clay will typically be mixed in the mined material despite avoidance of distinct clay layers. Discharge of these fine materials, suspended in the seawater overflowing from the hopper would cause turbidity plumes at the depth of discharge. The daily increment of new plume in this example would consist of 60,000 tons of water and about 200 tons of material finer than 200 mesh. Because the fines will stay suspended for days, the impact of daily activity of surface discharges could be considered cumulative. The blanket of fines would settle gradually to the seafloor as it travels with the currents, building up a very thin veneer over a large area. Discharge near the seafloor would result in a thicker layer over a smaller area.

Various methods exist to control turbidity and others are being developed. Existing methods usually rely on controlling the depth and direction of discharge, but the Marine Mining Panel of the U.S.-Japan Cooperative Program in Natural Resources recently tested a technique to control the formation of bubbles in the discharge streams to reduce the settling time for particulates (Marine Mining Panel, 1984). This Japanese-developed Anti-Turbidity Overflow System (ATOS) was tested at a typical dredge site off the coast of Japan to determine its potential for control of both surface turbidity and sediment dispersion. The system appears to work well in course-grained sediment. Data from tests in finegrained sediments are still being evaluated.

Trailing suction dredges, if modified for great depths, can also be used to mine deep sea manganese nodules. Operating characteristics and environmental data for this application are well documented (NOAA, 1981).

3.1.3 Crust miner

Recent interest in manganese oxide crusts containing relatively high values of cobalt, and in some cases platinum, has led to proposals to develop the deposits. The manganese crusts vary in thickness from mere stains up to about 15 in thick and cover a variety of substrate rocks ranging from hard basalt to weak hyaloclastite. The physical properties of the crusts are similar to a hard coal. The crusts occur extensively on the Pacific seamounts and submarine ridges at depths between 2,600 and 7,800 ft. The mining system primarily proposed for this work is a vessel equipped with a hydraulic lift system with an active bottom miner (Halkyard and Felix, 1987). The miner would be a self-propelled tractor, controlled from the surface vessel. The miner would be capable of breaking and removing the thin crust from the underlying rock and feeding it to the hydraulic lift system through a hydrocyclone to separate entrapped substrate (figure 5). The roughly cleaned ore would be pumped to the surface vessel for further cleaning and transport to shore.

Potential environmental effects, as discussed in the EIS for the proposed Hawaii-Johnston Island OCS/EEZ lease sale (DOI and HI, 1987), are expected to be much the same as the effects of the dragline dredge.

3.1.4 Continuous line bucket dredge

This system (figure 6) has been tested for possible future use in recovering manganese nodules (Masuda et al, 1972) and is described in NOAA's EIS for deep seabed mining (NOAA, 1981). The continuous line bucket (CLB) may also be used for mining phosphorite nodules and slabs, and its use has also been proposed for cobalt crust mining.

The CLB's environmental disturbances would be similar to those of the dragline dredge, except that the latter would involve discrete episodes of bottom disturbance and the CLB system would be continuous.

3.2 Excavating

Mineral deposits that are located mostly within the seabed may be removed by excavation. These deposits include thick deposits of sands; metalliferous muds; layered or disseminated deposits of unconsolidated placer minerals or overlying bedrock; and deposits of consolidated minerals in vein, tabular, or massive form, which may extend for considerable distances into the bedrock. The mining system used will depend largely on the ease with which the material may be excavated and removed from its surrounding environment, on the water depth, and on the climate in the area of operations (Cruickshank et al., 1969; Cruickshank, 1987). Six examples of seabed mining operations are presented here that range

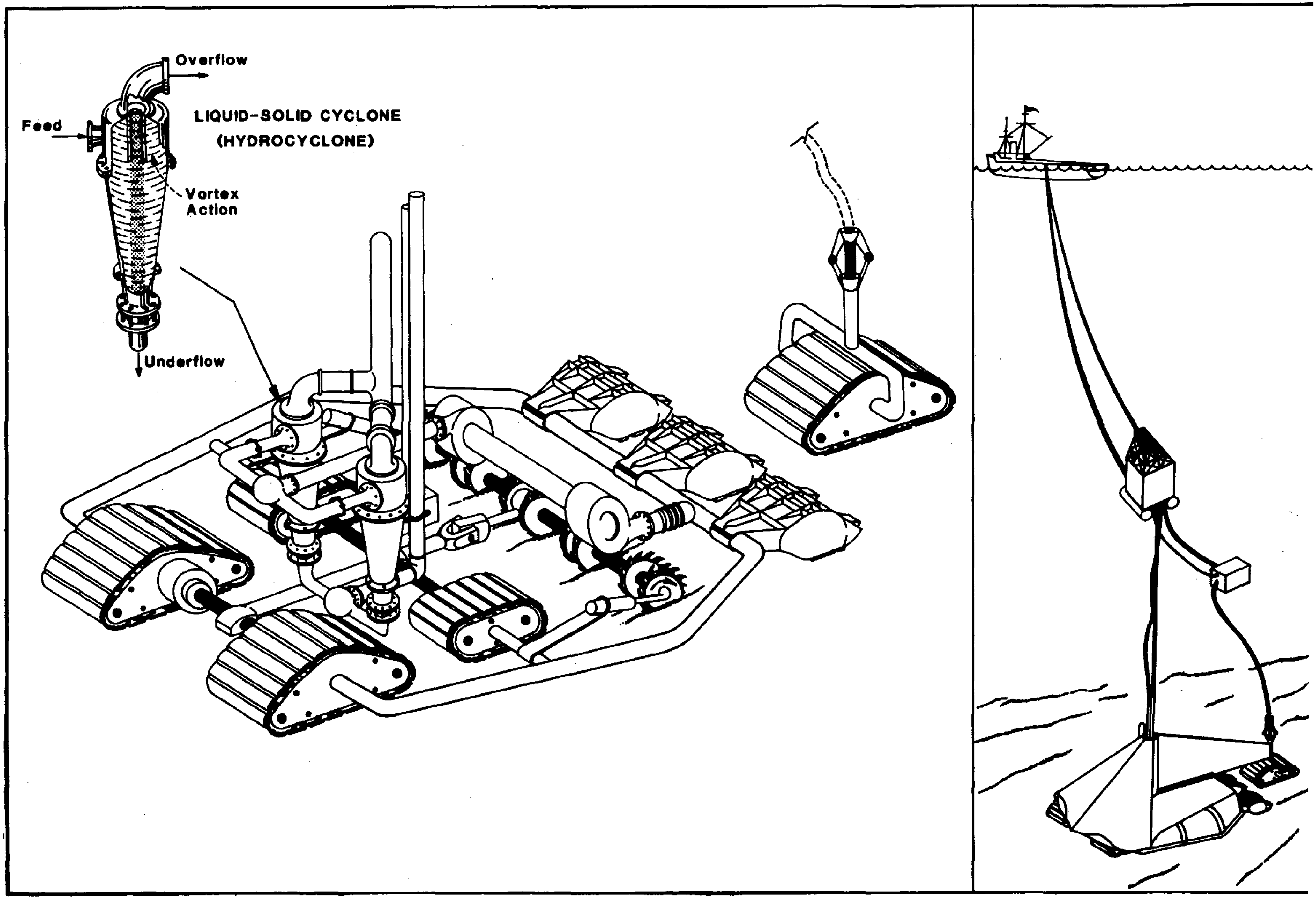
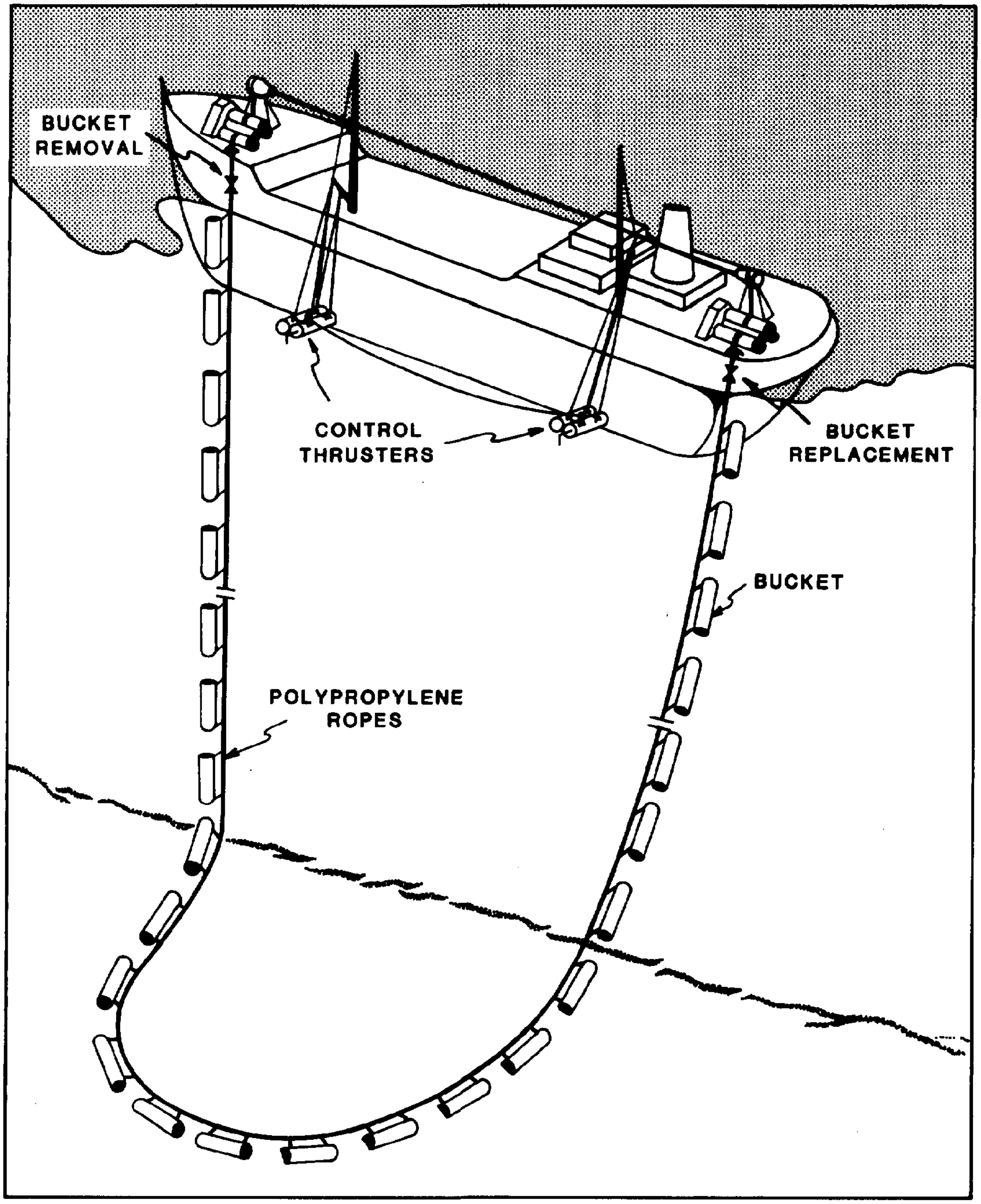


Figure 5 - Crust miner



TOP VIEW

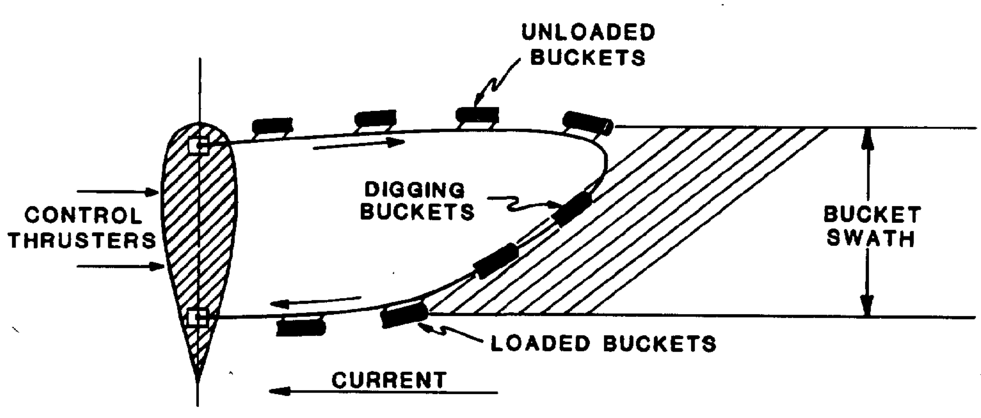


Figure 6 - Continuous line bucket dredge

from the excavation of free-flowing materials to the excavation of hard rock.

3.2.1 Clamshell bucket

Clamshell buckets have been used to mine sand and gravel in Japan and tin in Thailand, and to sample phosphorite off New Zealand. The buckets are mechanically actuated to bite into the seabed and remove material (figure 7). The need for multiple cables to actuate the grabs can cause complications, particularly in heavy seas where wave compensating devices may also be needed. Moreover, the clamshell is inefficient in clearing bedrock of fine materials. It is best suited for excavation of large-size granular material where accuracy of positioning is not important. The size of buckets may range from a few cubic feet to as much as 10 yd^3.

The action of the grab on the bottom stirs up any fine materials present and these also tend to wash out during the lift to the surface. Where washout is of major significance, it may be prevented or reduced by placing a canvas or plastic hood over the bucket.

3.2.2 Bucket ladder dredge

The bucket ladder dredge is most efficient for excavation of deposits containing boulders, clay, and/or tree stumps and weathered bedrock (figure 8). Dredges of this type have been used successfully all over the world for mining gold, tin, and platinum placers, and diamonds, although their use offshore has been limited to gold and tin. They are frequently used for clearing harbors because of their capability for digging into broken rock and coral. The bucket ladder delivers a virtually water-free product to the mineral dressing plant on board the dredge. Discharge of water from the shipboard operations is limited to that needed to concentrate the valuable constituents by techniques based on the use of flowing water to remove the less dense materials. In the case of gold, the bulk of concentrate recovered is only a few parts per million so that virtually all the material removed from the deposit is returned to the seabed.

Considerable turbulence accompanies these operations, which may involve up to 6.4 million yd^3 of material per year. Bucket ladder dredges are limited to depths of about 150 ft and rarely operate at depths over 65 ft. Few of these dredges have been built for offshore mining in the last 30 years, and it is likely that they will be superseded by the bucket wheel suction dredge.

3.2.3 Bucket wheel suction dredge

Bucket wheel dredges use a small diameter bucket wheel mounted on the suction ladder to excavate material. This combines the best aspects of the bucket ladder and suction dredges (figure 9). Very high torque or digging power can be applied to the wheel, which can deliver the excavated material directly into the mouth of the suction pipe for transport to the sea surface. Digging capability is equal to the bucket ladder with respect to ease of digging and bucket capacity, while the depth capability is greatly increased (Anonymous, 1984).

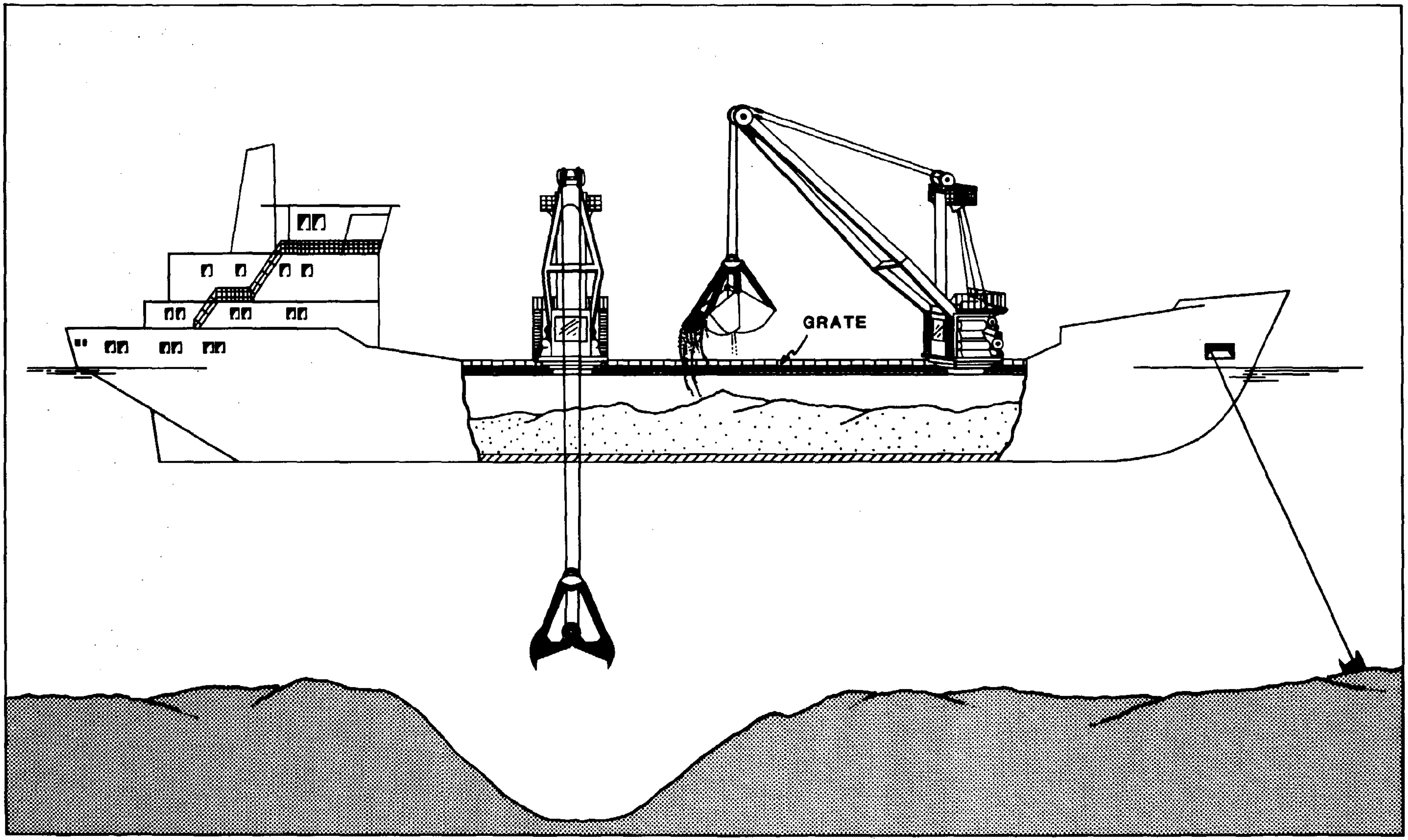


Figure 7 - Clamshell bucket dredge

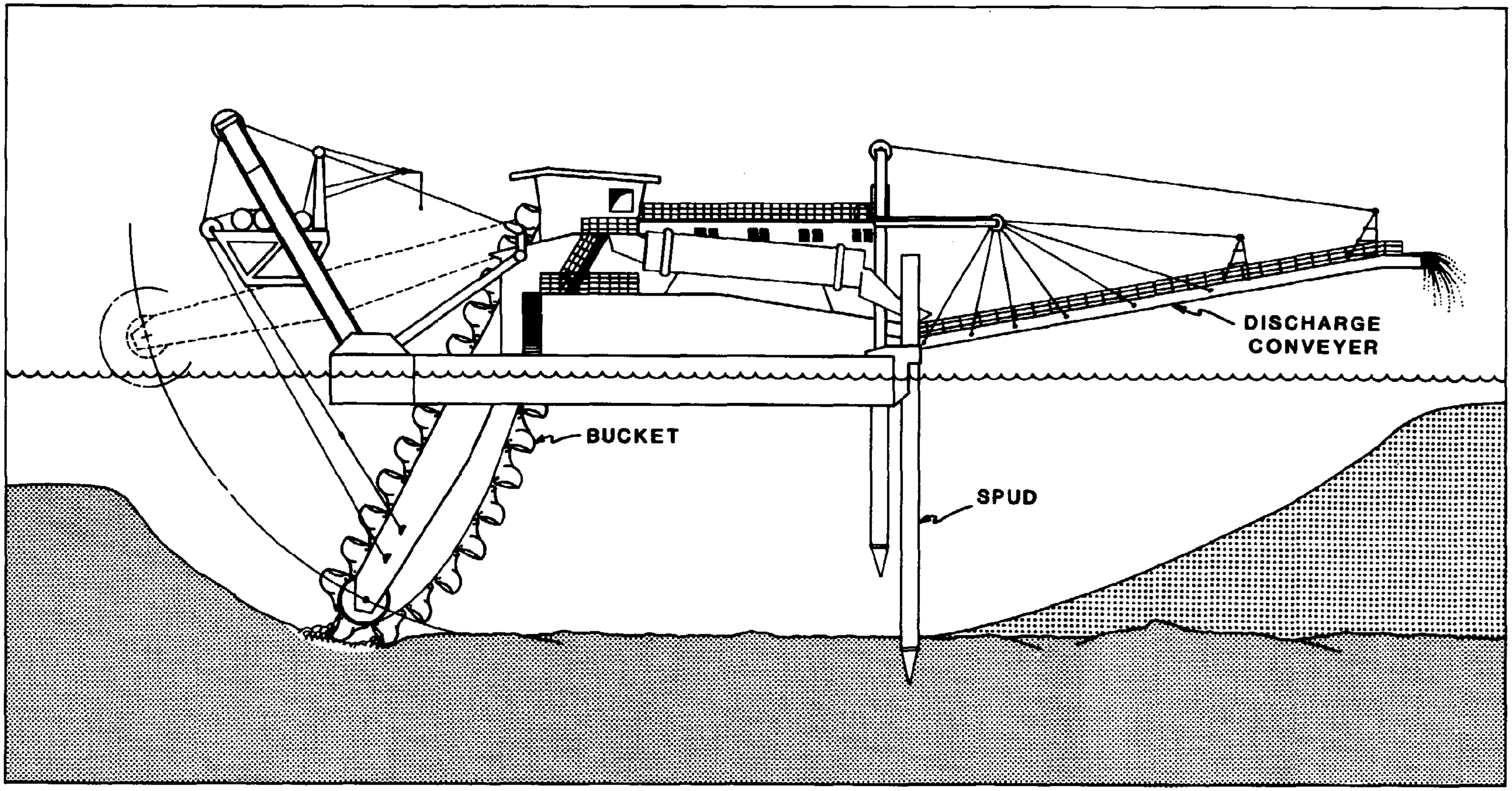


Figure 8 - Bucket ladder dredge used to mine gold in sheltered waters

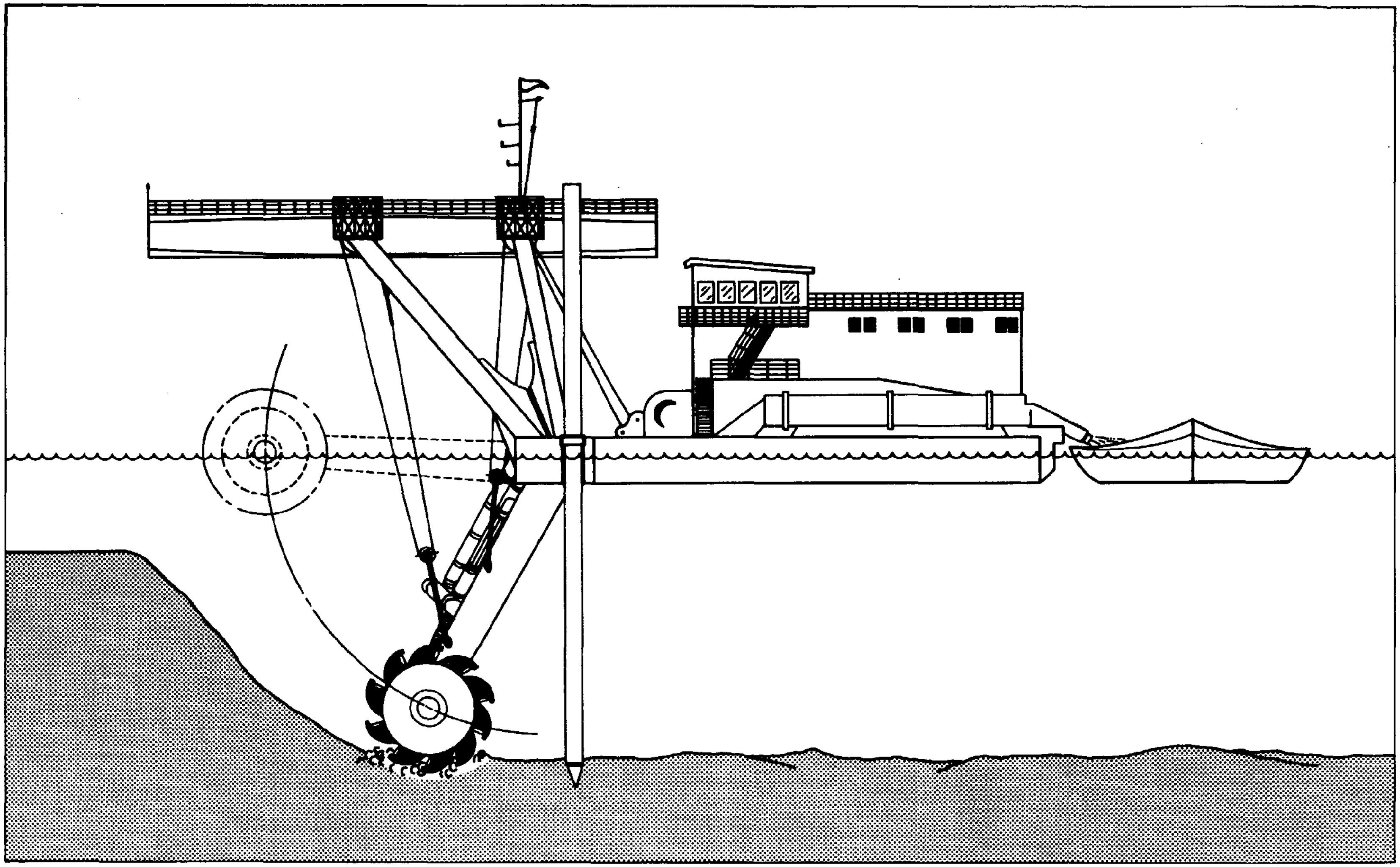


Figure 9 - Bucket wheel dredge for use in sheltered waters

The combination of simultaneous digging and suction at the seafloor reduces bottom turbulence, and provides the option to either treat the ore on the vessel or pipe it to shore. Other disturbances would be similar to those from other suction dredges.

3.2.4 Anchored suction dredge

Anchored suction dredges (figure 10) are widely used in Japan for mining sand and gravel at depths less than 100 ft. These dredges have been used in Britain as well, although the vessels built since 1980 are virtually all trailing suction dredges (Drinnan and Bliss, 1986).

In contrast to the trenches left by trailing suction dredges, anchored suction dredges leave pits in the ocean floor. These tend to fill much more slowly than the trenches, and are a greater source of problems for bottom trawlers. However, since fish often aggregate at scarps and other irregularities on otherwise flat bottoms, isolated pits may be considered assets by recreational fishermen. The rate at which the pits fill is a function of the size of the hole, the type of material remaining, and the currents. Holes in gravel, for example, are estimated to take 25 years to fill, while trenches in sand may fill in a matter of hours or months (Drinnan and Bliss, 1986).

An anchored suction dredge has also been tested for mining metalliferous muds at a depth of 6500 feet in the Red Sea (figure 11). This deposit consists of about 700 million tons of zinc, copper, and silver-rich muds in a small, enclosed basin. The mud has the consistency of shoe polish and is about 35 ft thick at the mine site. Mining involved the conversion of a deep drilling oil exploration vessel (the SEDCO 445) to carry a specially designed mud pump and delivery pipe that was lowered to the seabed in a manner similar to the lowering of a drill pipe. The pump was vibrated into the mud, with a water jet to fluidize the material, and the ore pumped to the ship for treatment. Approximately 20,000 yd^3 of muds were retrieved from 4 sites over a period of about 6 weeks. The muds were dewatered and subjected to froth flotation on board the vessel. The effluent from both operations was discharged through a pipe at a water depth of 1300 feet. All operations were fully monitored to observe effects on the water column and the biota.

In their report of the experiments, Mustafa and Amman (1981) observed build-up of a highly diluted diffusion cloud at about 3000 ft. They concluded dilution would be so extensive that a concentrated pile of tailings on the deposit would not occur, especially if a disposal depth of 1800-2400 feet were chosen. Commercial mining operations in the Red Sea using the anchored suction dredge may involve the removal of as much as 3.5 million tons of material per year of which over 90 percent would be returned to the sea. Environmental effects are further discussed in Thiel et al. (1986).

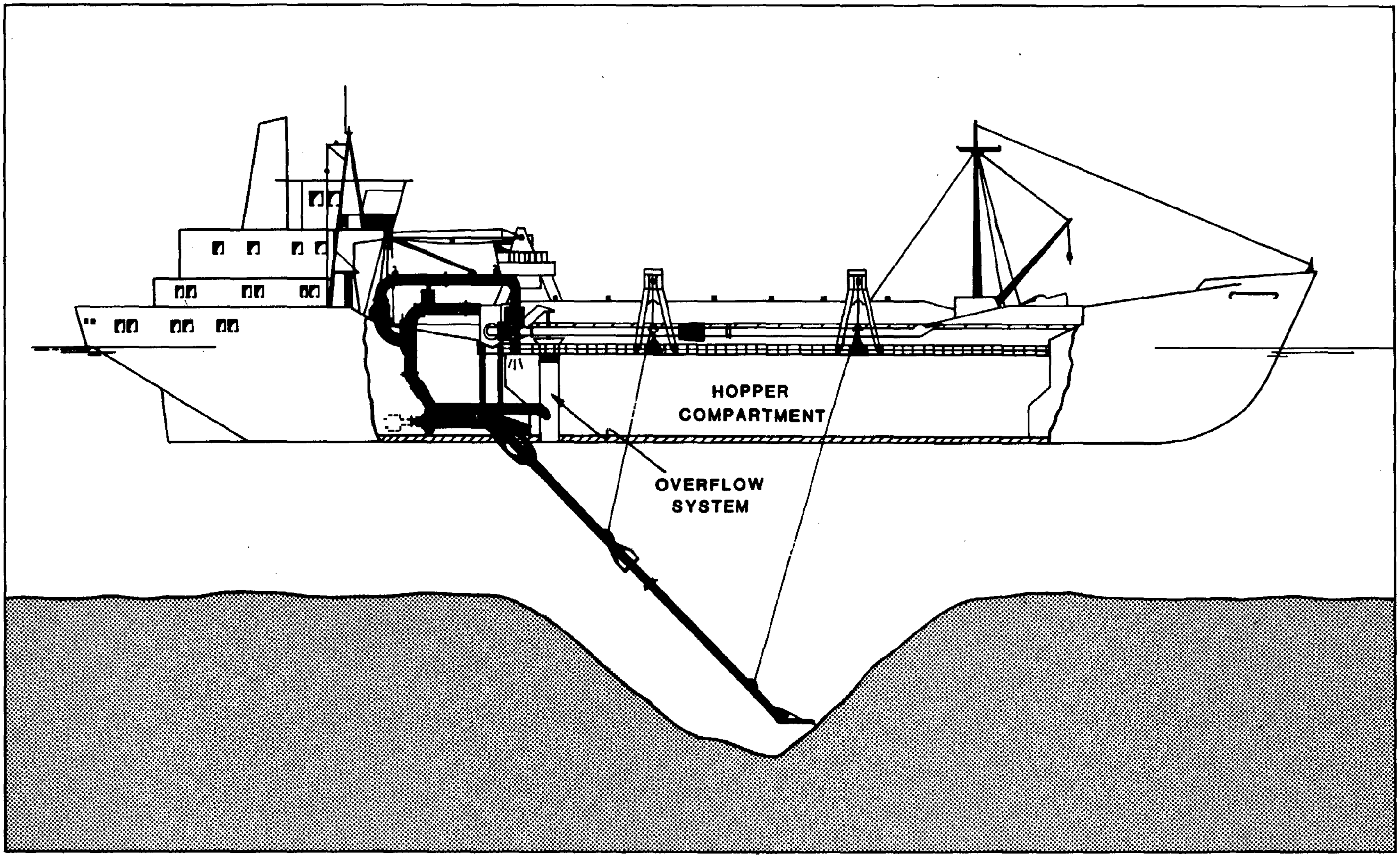


Figure 10 - Anchored suction dredge (shallow waters)

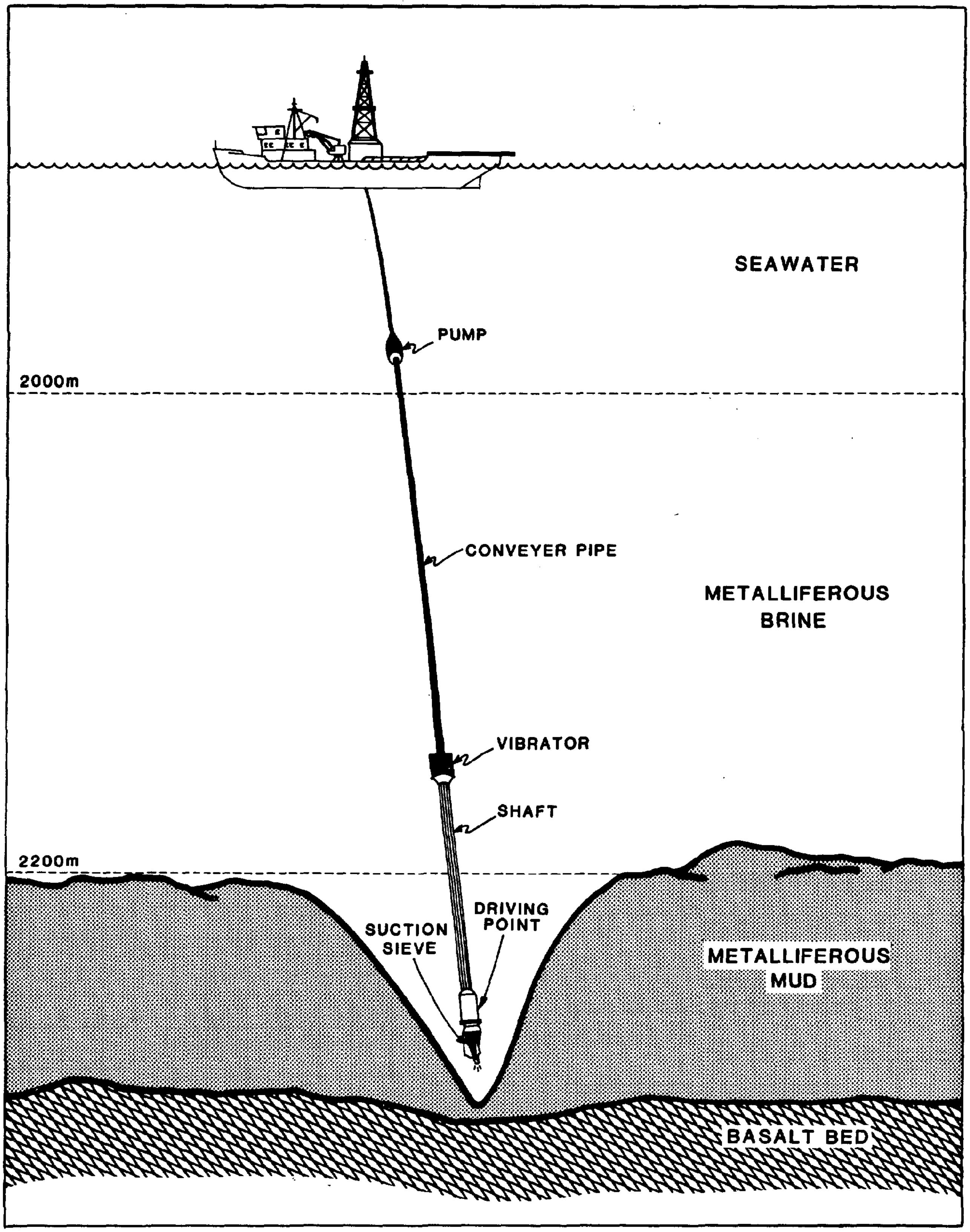


Figure 11 - Anchored suction dredge (deep sea)

3.2.5 Cutterhead suction dredge

Typically cutterhead suction dredges are used to excavate fairly compacted, granular materials in water less than 100 ft deep. The rotating cutterhead is usually an open basket with hardened teeth or cutting edges somewhat like an oversized dentist's drill (figure 12). The end of the suction pipe is normally located within the basket. In standard practice, the dredge is swung back and forth in an arc pivoted from a large post or spud attached to the stern. The dredge cutterhead cuts downward a short distance with each swing. Because the cutter rotates in one direction only, the bite is much stronger on one swing than the other. In mining for heavy minerals, the action of the cutter tends to disintegrate the material, allowing heavy minerals to separate, fall below the cut, and be left on the seafloor. Cutter suction dredges have never been used successfully for mining gold, although they have been widely used for mining cassiterite (tin placers) in west Thailand, where the deposits are rich enough to economically sustain the inefficient cleanup.

Suction dredges circulate large quantities of slurry that must be decanted on board the dredge or pumped ashore by pipeline. In either case, there is a significant discharge of water containing fine particulate materials. Treatment of the decanted solids may be unnecessary for construction sands and gravel, but may be required for heavy minerals. The valuable constituent or concentrate from these ores will rarely amount to more than a few percent of the materials mined. Therefore, as much as 95 percent of the material dredged from such placers must be disposed of at either the mine or the shoreside treatment site.

The cutterhead suction dredge may also be equipped with a multiblade ripper to cut into moderately consolidated rock. Present use is limited to the excavation of soft rock, such as coal and shale. However, advances in rapid tunneling technology suggest that rock cutterheads could be designed for medium strength rocks, such as sandstone and limestone (Hignett and Banks, 1984).

3.2.6 Drilling and blasting

Deposits that are too hard to excavate by dredging must be broken by other means. The normal system for excavating hard deposits is to drill into the deposit and blast with explosives. Fracturing using highly pressurized fluids is also possible, but would represent very special and rare cases, and are not considered here. Blasting of the material is only an intermediate step, and would be followed by the gathering and lifting of the ore by one of the methods previously described. Blasting operations are designed to expend as much force as possible on fragmenting the ore so the water column effects are much lower than those from equivalent, unconfined explosions.

Drilling and blasting for offshore mining is rare, but may be exemplified by the Castle Island Mine operations in the Gastineaux Channel in southeast Alaska (figure 13). That deposit was a massive vein structure of barite which outcropped on the island. Mining involved deepening the mine pit to as

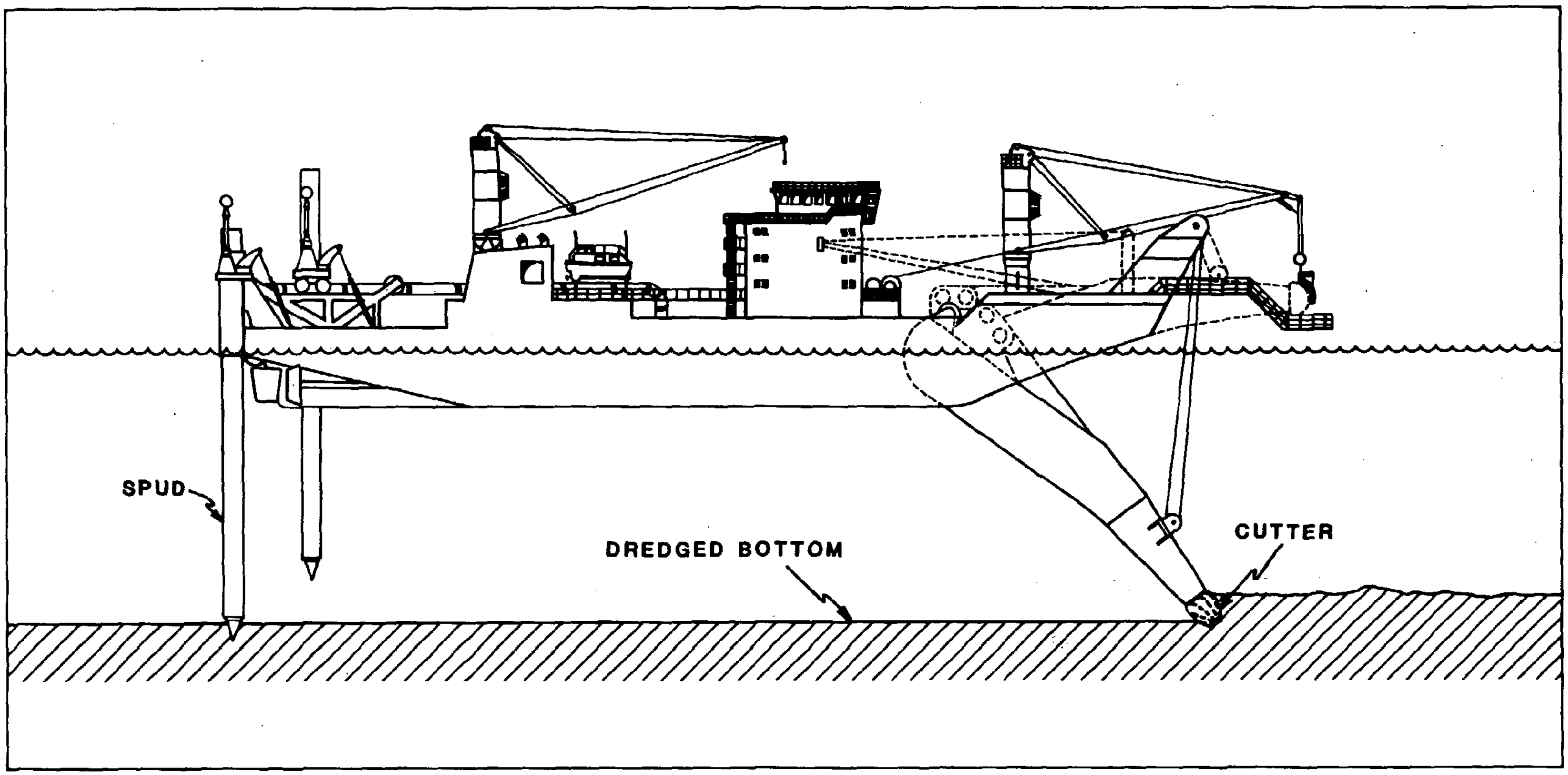


Figure 12 - Cutterhead suction dredge

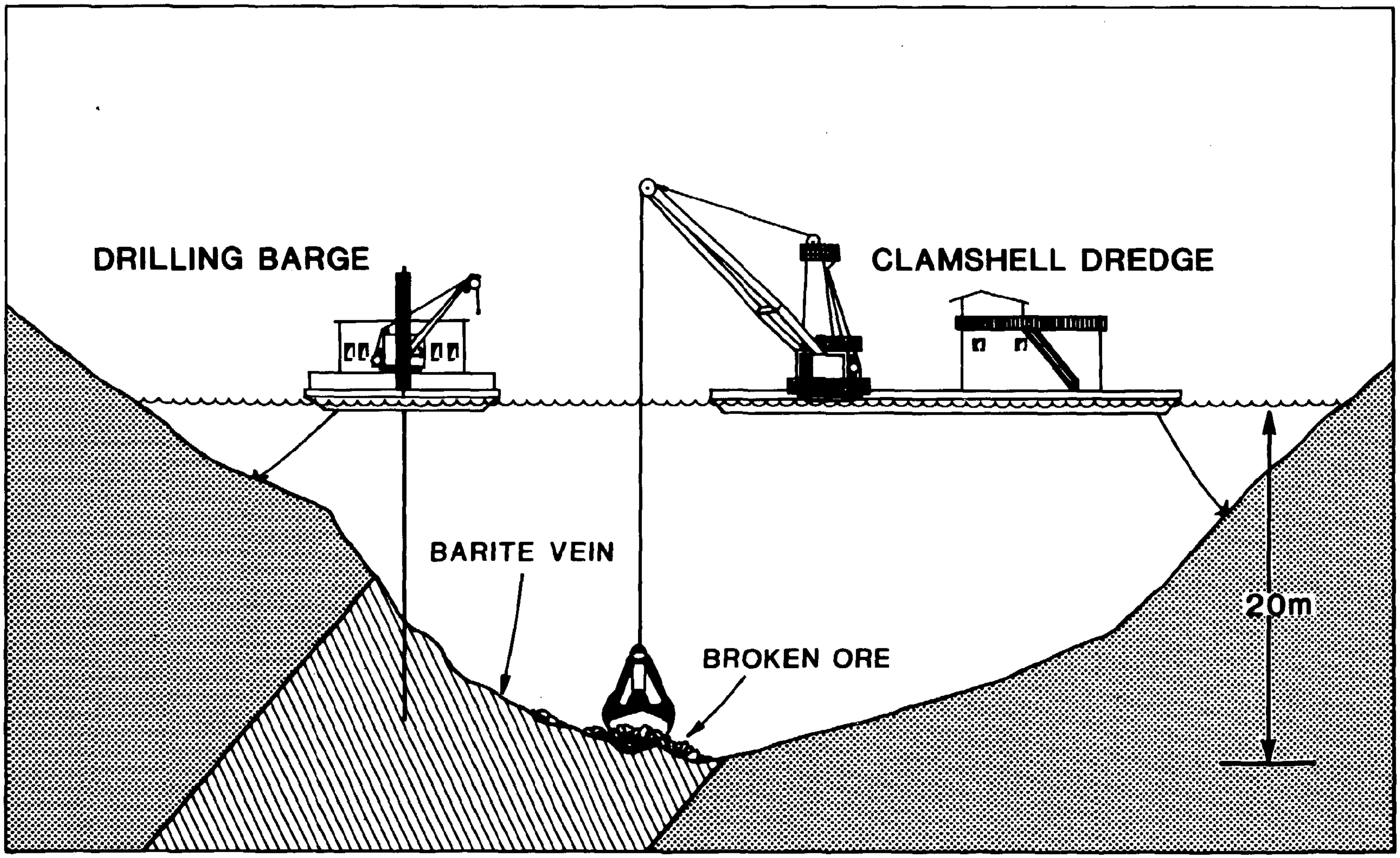


Figure 13 - Working a hard rock deposit from a floating platform

much as 100 ft under water using conventional drilling and blasting, followed by excavation of the broken ore with a barge-mounted clamshell dredge. Blasting took place every few weeks at the most. Localized fish kills were reported. Traces of fine barite were noted in the bottom sediments as much as 0.6 mi down current from the operations, but no indication of any effect on the biota was apparent (Thompson and Smith, 1970).

With respect to the possibility of mining deep seabed deposits that require fragmentation, many more aspects need to be examined. Technically acceptable means of drilling and fragmenting hard rock in deep water have not yet been developed. However, methods of gathering and lifting the fragmented material may be assumed to be similar to the methods developed for deep seabed nodule mining.

3.3 Fluidizing (slurries)

Under proper conditions, certain types of unconsolidated or marginally consolidated mineral deposits may be mined as a fluid slurry through a drill hole penetrating the seafloor. Subseabed sand was mined in this way in shallow waters offshore Japan in 1974 (Padan, 1983), and recent onshore experiments in Florida proved the capability of this approach in recovering phosphate from beneath thick overburden (Savanick, 1985). In this instance, a borehole was drilled from the land surface to the base of the ore body, then a water-jet cutting system was inserted through the borehole and used to fragment the loosely consolidated phosphate (figure 14). At the same time, a downhole slurry pumping system recovered the phosphate through the borehole, thereby creating a waterfilled cavity about 18 ft in radius. After mining was completed, the cavities were backfilled with sand to prevent ground subsidence. A U.S. Bureau of Mines study found this system to be cheaper than conventional land mining systems if the overburden is at least 150 ft. thick (Hrabik and Godesky, 1985). In the recovery of sulphur, super-heated water is pumped into the deposit to melt the sulphur so that it may be pumped out of the ground.

Environmental effects are primarily associated with the installation and movement of mobile drilling platforms, disposal of drill cuttings and any waste rock that can not be returned to subsurface, and release of any slurry or processing waters that are not recycled. (Recycling of slurry waters is anticipated to occur to a substantial degree).

3.4 Fluidizing (solutions)

Hard rock deposits that are amenable to hydrometallurgical treatment of their ores are potentially extractable by fluidizing methods (figure 15). The valuable constituent is dissolved in place and the pregnant solution is removed through a borehole. There are major problems in dealing with toxic or corrosive solvents used to enlarge fractures to provide a flow path for the solvent through the deposit and to selectively extract the desired metals in complex ores.

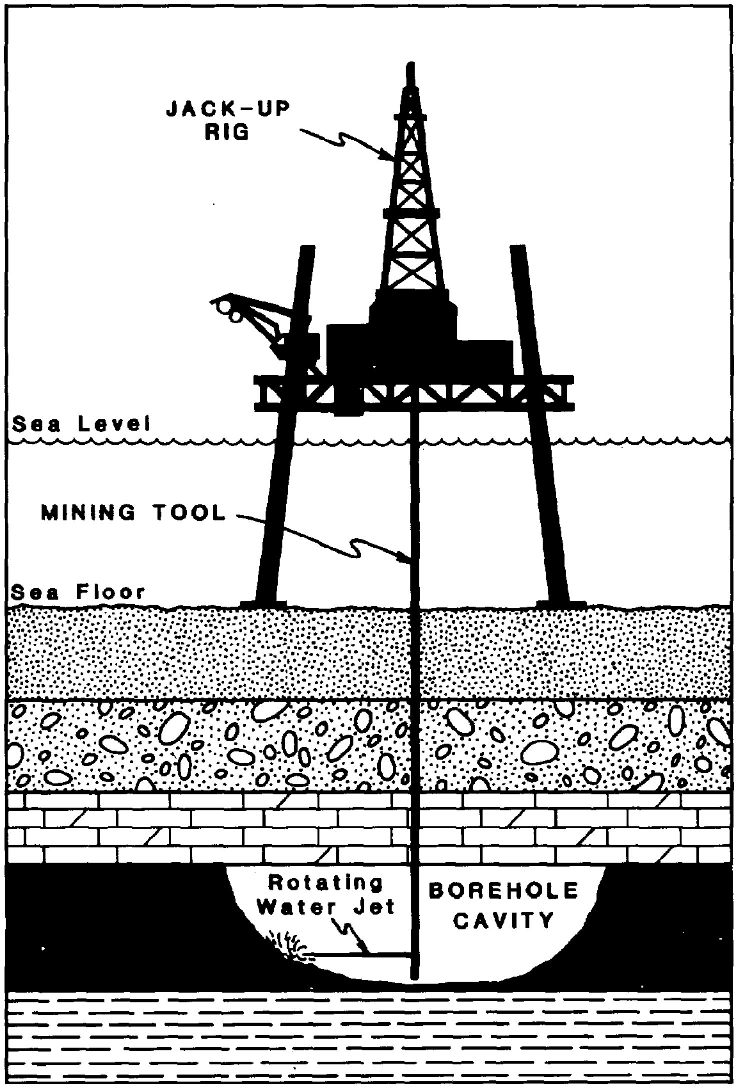


Figure 14 - Fluidizing (slurrying)

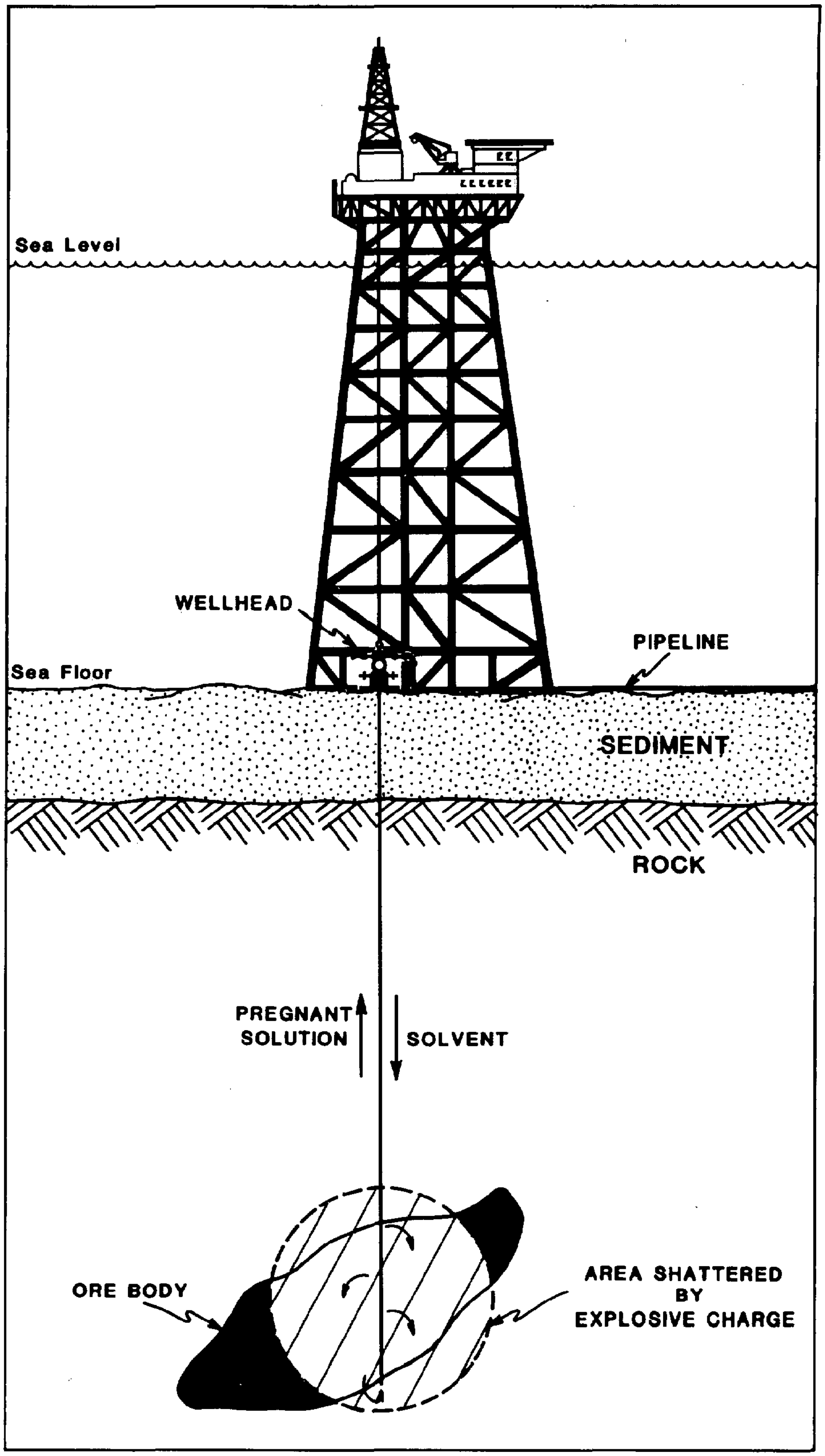


Figure 15 - Fluidizing (leaching)

These problems are being overcome on land, however, and the methods developed there should be applicable in more sophisticated form to seabed deposits. Environmental effects during normal operations should resemble those of slurry mining.

Effects of accidental spills of solvents would depend on the nature of the solvents and the sites impacted, but should be localized so long as the solvent is water soluble, due to the rapid dilution prevailing in the oceans and the buffering capacity of seawater.

3.5 Tunneling beneath seafloor

Underground mining by tunneling is commonly practiced in subsurface hard rock. In certain cases, subseabed deposits of bedded coal, potash, and ironstone, as well as veins of lead, copper, and tin have been mined by conventional underground methods. Entry to these mines is either from the shore or from natural or artificial islands in shallow waters (figure 16). The location of the mines in the seabed only slightly adds to conventional problems of access, safe overhead cover, and ventilation. The effect on the environment is similar to that for any shoreside mine. The possibility of developing underground access through seabed airlocks has been considered for special cases but is not considered further here.

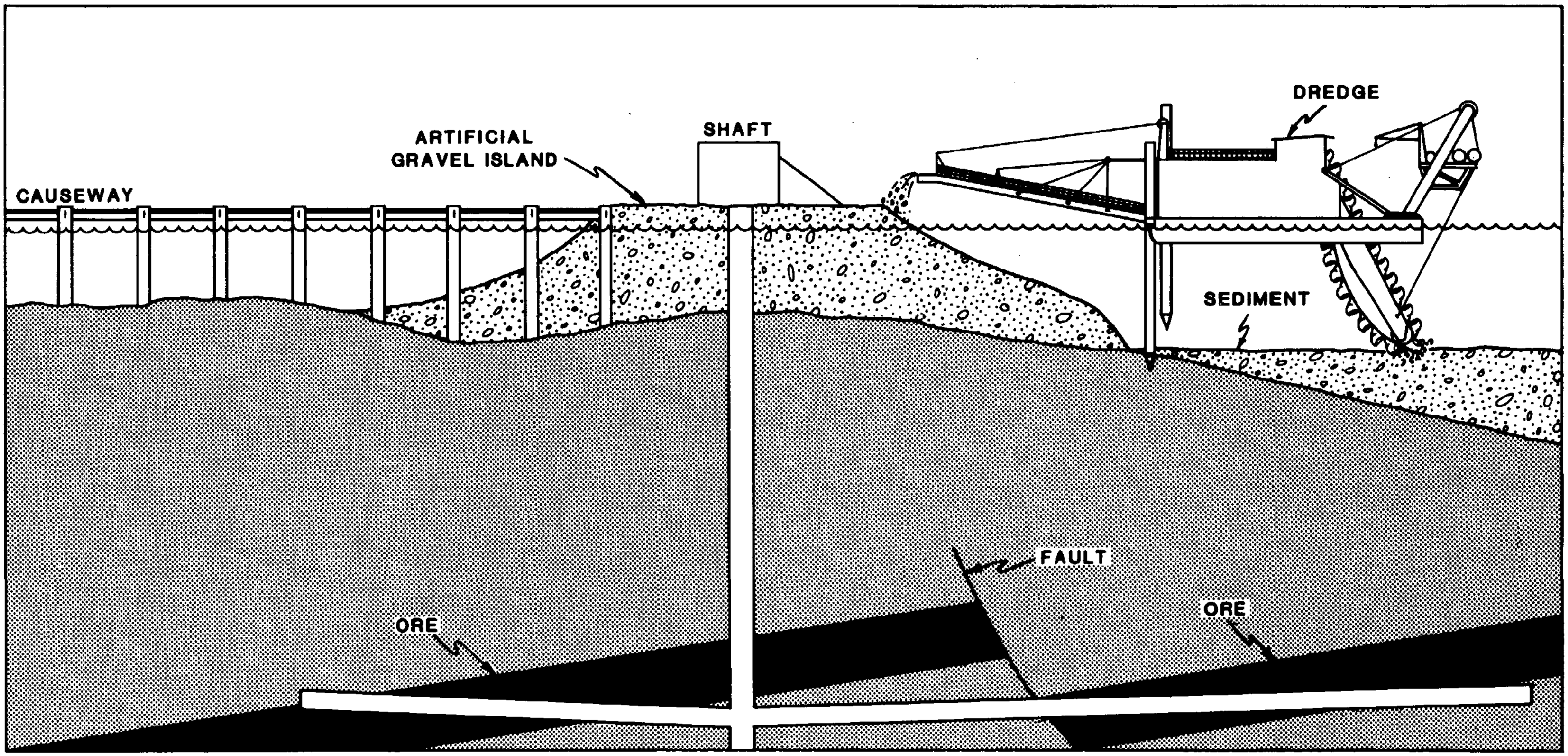


Figure 16 - Mining with the aid of an artificial island

Although there are many types of OCS mineral deposits, mining methods, and environments in which mining may occur, mining operations will affect the OCS environment in only a few ways. The principal effects are those shown in table 3. These forms of disturbance are not new. They individually or in combination result from trawling operations, harbor dredging, military manuevers, construction at sea, and in some cases, natural causes. However, mining will create new sources and new combinations of these disturbances, and the locations, durations, and intensities of these effects may be new.

On the seabed, one can routinely expect disturbance from ore collection. The seafloor in the path of the collection machinery will be raked, fragmented, suctioned up, or compacted as the ore is gathered. Should fragmentation by explosives be required, additional disturbances would be introduced into the marine environment by shock waves. Noise can be assumed to be a by-product of mining operations. The attenuation of the noise will depend on its frequency spectrum as well as the properties of the water masses through which it moves. In some forms of mining, the area near the mining machinery will be illuminated.

Movement of overburden or excavation of ore may create trenches or pits in, or mounds on, the seafloor. These mounds and depressions have implications for potential use conflicts and other environmental impact concerns that may persist after mining ceases.

Subsurface mines and slurry mining cavities have the potential of causing seafloor subsidence or collapse, but these phenomena should be avoidable by proper mine design. In the case of borehole mining, involving the removal of ore in a slurry, the the resulting cavity can be backfilled with waste rock as in subsurface mines before the site is abandoned.

Seabed mining will create a turbidity plume at the seafloor to the extent that fine material is present on the seafloor, in the deposit, or is created by fragmenting or grinding rock as part of mining. The largest seafloor turbidity plumes plumes may be created by mining systems designed to reject fine material during pickup of the ore.

Surface turbidity plumes will be created by those systems designed to pump ore in a slurry to a surface vessel and then allow the excess water to overflow to the sea. The size of the plume will vary in proportion to the amount of fine material unavoidably recovered with ore. The fines will tend to remain in suspension in the mining vessel and be discharged with the slurry water. Water column environmental concerns generally focus on either these suspended particulates or dissolved substances. Turbidity plumes move away horizontally from their sources with the current and are rapidly diluted, but the existence of plumes often can be detected far from the mine site.

The fine particulate material suspended in plumes eventually rains to the seafloor, resulting in a thin layer of fine material over a large area. The area affected can be minimized by subsurface discharge or other techniques that force the particulate material to settle closer to its source, resulting in a heavier accumulation over that smaller area.

The environmental impacts of mining in the OCS encompass both the effects of mining itself, as depicted in table 3, and the effects of transport, beneficiation and refining of the ore mined. These latter, nearshore and onshore sources of impact will often be the more significant sources of impact, but they are beyond the scope of this document with its focus on impacts in the OCS. However, onshore sources of impact will be considered in the lease sale EIS's the Department of Interior will prepare as well as any environmental documentation required by the affected States and localities.

The effects on organisms of fragmentation/collection, excavation, and subsidence can be characterized as near-field, that is, they are essentially restricted to the mine site, although exceptions are possible. For example, species extinctions and even regional impacts for example, seem unlikely, but significant impacts on regional populations of some species could result if breeding grounds were mined. The potential for events of these magnitudes, however, is carefully considered during the preparation of EIS's or other environmental reviews for leasing and mining proposals, and should be avoidable.

Effects of plumes and sedimentation--unlike the effects of fragmentation/collection, excavation, and subsidence--can be characterized as far-field since they may be felt well beyond the mine site. The probability and severity of resultant biological consequences depends on the characteristics of the specific mining operation, the geologic setting, and the geographical location of the mining activity. It is possible, however, in spite of such uncertainty, to use the data base created by several past projects to identify those far-field effects that are more likely to be of concern. These include NOAA's Deep Ocean Mining Environmental Study (DOMES), NOAA's New England Offshore Environmental Study (NOMES), the Army Corps of Engineers' 5-year Dredge Material Research Program, studies of offshore sand and gravel mining operations in the United Kingdom, and basic research studies of factors affecting impact and recovery from specific disturbances. These studies, which encompass a variety of offshore environments suggest that effects on organisms living in the water column are likely to be minor in most areas of the OCS.

Effects at the seafloor--particularly those resulting from the resedimentation of the benthic turbidity plume, the actual destruction of the biota, and the change in seafloor topography--will generally be more important than effects of changes in the water column. This conclusion is founded upon both observations of dredging operations and laboratory

Table 3 Normal environmental disturbances [1]

Mining Methods		Seabed					Water Column	
Mining Approaches	Mining Systems	Fragmentation/ Collection	Excavation	Subsidence	Turbidity Plume	Resedimen- tation	Suspended Particulates	Dissolved Substance
Scraping	Dragline dredge	X			X	X	X	X
	Trailing suction dredge	X			X	X	X	X
	Crust-miner	X			X	X	X	X
	Continuous line bucket	X			X	X	X	X
Excavating	Clam shell bucket		X		X	X	X	X
	Bucket ladder dredge		X		X	X	X	X
	Bucket wheel dredge		X		X	X	X	X
	Anchored suction dredge		X		X	X	X	X
	Cutterhead suction dredge		X		X	X	X	X
	Drilling and blasting		X					
Fluidizing (Sub-Seafloor)	Slurrying			X				
	Leaching							
Tunneling Beneath Seafloor	Shore entry			X				
	Artificial island entry			X				

1 X= Disturbance expected. Magnitudes of the disturbances are also dependent on the nature of the mineral deposit and the amounts of fine particles present on the seabed. Closed circulation systems are assumed for slurrying and leaching. Open circuluaion would result in plumes and resedimentation.

studies of the effects of suspended materials concentrations. Given the relatively rapid dilution of suspended sediments and dissolved substances, their concentrations should fall within acceptable ranges near the point of discharge. Factors, both biological and nonbiological, that may affect the validity of this conclusion are listed in table 4, and each of these factors should be considered in the determination of potential environmental effects.

The sensitivity and natural resiliency of the benthic community is important in determining the recovery of the affected biota as a whole (ICES, 1975). Some species of organisms will likely be more affected than others because of feeding mode (e.g., filter feeders), life habit (e.g., surface dwellers), degree of mobility (e.g.,tube dwellers), or sensitivity of life stage (e.g., larvae). Those organisms living in an environment with episodes of high turbidity and sedimentation can likely withstand some disturbance. For example, oysters, which are filter feeders, are able to endure some increases in sedimentation (Macklin, 1961; Dunnington, 1968; Loosanoff, 1962), and benthic deposit feeders can burrow out from some increase in deposition (Nichols et al., 1978; Hirsch et al., 1978; Maurer et al., 1978). However, for both deposit and filter feeders, there are redeposition thicknesses and rates beyond which the animals cannot survive.

Several general, and numerous specific, factors have been found to be critical in determining the rate at which a disturbed area is recolonized by species that were previous residents. A mobile adult stage allows faster recolonization of large disturbed areas, especially if the larval stage is nonmobile (Levin, 1984; Dauer and Simon, 1976). The season, duration, and areal extent of the disturbance can be critical, if the disturbance occurs during a period when stability of the seafloor is important to the survival of certain life stages of a species. For example, some fish lay eggs on the seafloor and would be very sensitive to mining before the eggs hatch. Hence, changes in the shape of the seafloor could affect the survival of members of even those species that spend most of their life in the water column. These examples illustrate the multiplicity of factors that may influence the degree of impact from OCS mining. Early identification of those factors are important in determining the degree of impact and recovery rates and allows mining proposals to be developed that consider potential impacts and possible mitigating measures. However, until the areas of mining are known, it is of limited value to try to predict further the severity of impact from a particular mining activity.

5.1 Physical impact concerns

Physical impacts of concern in the OCS will generally be those that impact marine organisms, fisheries, other commercial uses, or military operations. Nearer shore, in State waters, potential impacts on coastal erosion will require careful appraisal. The major concerns regarding purely physical impacts will be space use conflicts and poor housekeeping. Fouling of nets on discarded mining

Table 4 Key Factors Affecting Degree of Environmental Impact

Plume Effects (swimming or floating species)

Nonbiological

1 - areal extent
2 - season
3 - duration
4 - concentration
5 - currents
6 - water depth

Biological

1 - stage of development when impacted
2 - physiological sensitivity of species
3 - dispersal ability of species
4 - feeding mode
5 - dependency on light
6 - geographic range

Resedimentation Effects (benthic species)

Nonbiological

1 - degree of alteration of substrate type
2 - depth of redeposition
3 - duration
4 - season
5 - areal extent
6 - currents
7 - water depth

Biological (primary effects)

1 - stage of development
2 - physiological sensitivity of species
3 - dispersal ability
4 - feeding mode
5 - life habit (e.g., burrowers)
6 - geographic range

gear, displacement of individual fishermen, unannounced activity by miners, and fouling of gear in holes left by mining have generally been the major concerns in Britain (Drinnan and Bliss, 1986). However, these concerns have administrative and technological solutions.

Ore collection will invariably be a source of physical impact. The seabed in the path of the collection mechanism will be raked, broken, and/or compacted as the ore is gathered. If the ore needs to be fragmented by explosives, shock waves will create additional disturbances. In some forms of mining, the area near the mining machinery will be illuminated. Usually the effects of fragmentation and collection will be essentially limited to the mine site and the period of mining. Other effects such as the creation of trenches, pits or mounds on the seafloor may affect the biota and fishery operations for years.

Alternatively, boulders may be uncovered, forming permanent obstructions that snag fishing trawls. In this respect the French have experimented with abutting dredging tracks to obtain a flat seabed. Also, in some cases, rejected materials can be guided back into the collector tracks immediately behind the mining machines. Similarly, use of trailing suction dredges, which interfere much less with bottom fisheries than do anchored suction dredges, reduces conflicts with commercial fisheries (Drinnan and Bliss, 1986).

Large excavations can also lead to coastal erosion if the wave patterns and sediment movements near shore are changed sufficiently. These effects are being studied by the Army Corps of Engineers, but an interim guide to safe practices can be obtained from British experience. In their coastal zones, dredging seemingly causes no problems in water depths greater than half the normal wave length, or more than one fifth the length of extreme waves. Dredging in waters over 20 m (about 60 ft) deep is usually approved with only a desk review. Proposals for dredging in 10-20 m get more detailed review and may require site specific information. Proposals for dredging in waters shallower than 10 m may require substantial study (Drinnan and Bliss, 1986).

Both the scraping and excavating approaches to mining can also change the character of the substrate by exposing materials with different properties. For example, if exposure of silts and clays is a concern, it may be necessary to require that the bottom portion of the layer being mined be left in place to minimize such change. However, for sand and gravel mining and for some other minerals, the economics of mining may provide strong incentives not to expose silts or clays. If so, such regulations may be unnecessary.

Subsurface mines and slurry mining cavities may cause local seafloor collapse or subsidence, possibly leading to coastal erosion or changes in sediment patterns, but this phenomenon can be avoided by proper mine design. In the case of borehole mining, cavities are likely to be water-filled during the mining, and waste can be injected into the cavity before the site is abandoned. Both practices reduce the potential for collapse of the rock overlying the cavity and waste injection reduces the volume of waste discharged at the surface.

Seabed mining will create turbidity plumes at the seafloor as fine materials are resuspended or created during mining. The properties of the plume, particularly settling times of the particles, will depend on their size distributions, specific gravities and concentrations; which are also the properties of greatest biological significance. Size and specific gravity of the particles determine residence time in the water column and influence the potential for resuspension. The largest of these plumes may be created by mining systems designed to reject fine material during pickup of the ore. The chemical characteristics of the smaller, slower settling particles in these plumes generally will be similar to existing suspended sediment. However, they may differ if mining exposes an anoxic layer, because the solubility of adsorbed metals can differ greatly between reducing and oxidizing environments. The effects of such differences are likely to be local and brief due to rapid dilution by oxygenated waters. Rock fragments created by mining are likely to consist of relatively inert material and are less likely to be a source of dissolved metals than are resuspended sediments.

Surface turbidity plumes are created as wastes are discharged and will vary in proportion to the amount of fine material discharged and the disposal technique. The fines will tend to remain in suspension on board the mining vessel and be discharged with the slurry water, and, in a continuous mining operation, a continually renewed plume is present. Sediment concentrations in any one parcel of water decrease as the water mass moves away from the point of discharge, but each such parcel is replaced by another. A steady state then evolves in which high concentrations are always found near the discharge point even though the concentrations in each parcel are continually decreasing.

The fine particulate material suspended in plumes eventually falls to the seafloor, forming a thin layer over a large area. The area affected can be reduced by subsurface discharge or other techniques that force the particulate material to settle close to its source, but this creates a heavier accumulation in that smaller area. The appropriate sedimentation pattern, and thus the appropriate disposal methods, will depend upon the characteristics of the site, including the biota.

Field studies and modeling results indicate that plumes, both surface and benthic can be detected over distances on the order of kilometers, and, in certain cases, tens of kilometers. Plumes from coastal dredging typically are visible for only 1-5 km but may be visible up to 20 km (DOI, 1974). In the clearer oceanic waters beyond the continental shelf, reductions of light levels sufficient to measurably reduce rates of photosynthesis may be present for 30 to 50 km downcurrent (Chan and Anderson, 1981), and plumes can be measured up to 120 km from the point of discharge (Lavalle et al, 1981). However, detection of plumes at these distances requires the measurement of materials that are prominent in the discharge from the mining vessel, but are rare in natural waters. Manganese in the discharges of manganese nodule miners is an example (Lavelle, et al, 1981).

Measurable effects of sedimentation will be much more localized than those of plumes. Lavelle et al. (1981), for example, found that 90 percent of the sediments suspended by manganese nodule mining were redeposited within 70 m, even though the mine site was covered with clays that would be expected to form a plume of small sized, slowly setting particles. Thicknesses of the sediment layers resulting from mining were less than 1-5 mm at 200 m from the disturbed area, about 2-4 mm at 50 m, and 8 mm at 25 m. Thicknesses of resedimentation may be considerably higher in some mining operations, but the pattern of rapid decline in sedimentation as distance increases can still be expected.

In addition to the disturbances shown in table 3, mining will also be a source of light and noise. Since light is absorbed rapidly in water, and particularly so in turbid waters such as may occur near the mining equipment, the radius of the area affected will generally be a matter of meters or tens of meters. Noise will affect a larger area since sound propagates through water much more readily than does light and may carry well beyond the mine site. However, noise is generally not expected to be a significant problem.

5.2 Biological impact concerns

Biological impacts will occur on the areas actually mined, as immobile and slowly moving organisms are destroyed by the mining machinery. However, the areas mined are expected to be small relative to the total area occupied by the affected species. The areas affected by the turbidity plume and resultant sedimentation are considerably larger but still small relative to the total area of the affected habitat. The small scale of mining operations means that the offshore impacts generally will be limited in areal extent. However, since exceptions can be expected, assessments of the potential impacts of individual projects will be required to ensure minimal adverse impacts.

The most certain impacts will be the unavoidable impacts at the mine site as machinery moves across the seafloor to fragment, collect, or otherwise process ore or move overburden. Many organisms that cannot avoid the mining equipment will be destroyed. The significance of that destruction will be addressed in the site specific environmental analyses for proposed operations. However, because of the limited areal extent of near-field impacts, the less certain far-field impacts could be vastly more significant and so are stressed in this document. Section 5.2.1 discusses turbidity, 5.2.2 discusses sedimentation, 5.2.3 discusses explosives, and 5.2.4 discusses light and noise.

Additional, independent assessments of expected effects of OCS mining will be available in an analysis to be published in summer 1987 by the Office of Technology Assessment (OTA). A workshop associated with this OTA study concluded that surface and midwater effects should be minimal if appropriate precautions are taken. The workshop participants deemed the effects on bottom organisms would be the most pronounced. Extinctions, which are the severest form of impact; sublethal effects; and recovery rates were deemed to need continued study. These needs were felt to be particularly strong in the deep sea where the identities of the organisms and their life histories are generally unknown.

5.2.1 Turbidity

The principal biological effects of increased turbidity from mining are the interference with filter feeding, clogging of gills, and inhibition of photosynthesis because of decreased illumination. Enough variables are involved to give seemingly contradictory results when individual phenomena or laboratory data are discussed in isolation, but generalizations are feasible if one examines the impacts of actual dredging operations.

The effects of turbidity caused by mining in oceanic waters are localized and relatively mild because of rapid dispersal of particles. Nonswimming organisms will drift with the plume as it rapidly dilutes, but their exposure to high turbidity will be brief. Swimming organisms probably will avoid the areas of highest turbidity completely. If so, these organisms would be excluded from small portions of their geographic range for the duration of mining. For example, midocean discharges during tests of manganese nodule mining equipment resulted in near-ambient concentrations within 4 km of the discharge point (NOAA, 1981). Similar results generally prevail in the shallower waters of the continental shelf, although higher concentrations may occur.

Measurements by the French (Cressard and Augris, 1982), during an experimental dredging of sand and gravel in the Bay of Seine (depth 20 m), showed concentrations of 5 to 25 g/l of unknown duration. However, concentrations such as these tend to be highly localized and recolonization of such disturbed areas may be rapid. In the shallow waters of the Beaufort Sea, large dumping operations during construction of gravel islands produced downstream concentrations only about three times the ambient concentration of 8-12 milligrams per liter (mg/l) within 340 m of the site. Concentrations were only twice ambient levels within 1730 m. Similarly, concentrations of 100-300 mg/l at 100 m downstream of barge dumps were predicted for island construction in the Canadian Arctic (DOI, 1983b). These concentrations harm the more sensitive individuals of the more sensitive species, but not all individuals of even these species are likely to be affected. Concentrations that led to the death of 10 percent of the tested organisms in the Beaufort were 10 g/l or more for tolerant species and less than 1 g/l for highly sensitive species. Even this lower threshold is 3 to 10 times the concentrations measured 100 m downstream of barge dumps. The predicted or measured sediment concentrations a few hundred meters away from the dump site were generally 10 to 100 times below the lethal levels for even the most sensitive 10 percent of the tested populations (DOI, 1983b).

In addition to sediment concentrations, there are three other potential sources of concern. First, the presence of toxins in the sediments can greatly increase the adverse impacts of turbidity. However, the data showing such effects are based on studies of sediments from harbors and estuaries in which toxins, such as pesticides and heavy metals, are introduced to the marine environment and subsequently adsorbed to the surfaces of sediment particles. Such contaminants are rarely found in more than trace amounts in the OCS. Moreover, in natural mineral deposits exposed to seawater, the biologically active metals are in essentially insoluble forms and generally are biologically inert.

Second, fluid muds (fluff) may form near the water-sediment boundary and persist for weeks if there is insufficient circulation to disperse them. However, lack of circulation is rare in OCS waters, although fluff may form in coastal waters. Shell dredging operations in Galveston Bay, for example, resulted in a nearbottom mud flow with particle concentrations from 20 to 150 g/l that lasted throughout the dredging operations (Masch and Espay, 1967, from Peddicord, 1976). Such a condition could be a problem for fauna that are not equipped to move through this layer to reach the less turbid environment (Hirsch et al., 1978). However, the significance of this layer is partially a function of its thickness, a parameter which can be affected by the mining methods. The potential for fluid mud formation when fine, noncohesive materials are resuspended or discharged, along with the resulting hazards, will strongly depend on the site and the operating conditions.

Third, in all cases where mining involves the mechanical fracturing of the rocks, the particles produced are more likely to have sharper, more angular edges than resuspended bottom sediments. These sharp fragments may damage organisms more than natural sediments can.

Both laboratory and field observations have been made of various organisms under conditions of increased suspended sediments for various durations. The results, when compared with increased concentrations expected in the water column, suggest that these effects may not be a concern if the dilution factor is high and there are no exceptionally sensitive bottom communities in the area. For instance, a study of animals from San Francisco Bay found that at least 90 percent of the animals in most of the 18 species tested were alive after 10 days exposure to concentrations of 100 g/l kaolin clay suspensions (Peddicord, 1976). Even the more sensitive species were only adversely affected by tens of grams per liter of processed bentonite clays over several days time. However, these experiments did show that the sensitivity of some species to bentonite increased with higher temperatures (e.g., 18°C) or lower oxygen concentrations (Wakeham et al., 1975), suggesting that in the San Francisco Bay, seasonal changes in these two parameters may be important in determining the severity of impact from dredging and disposal. However, Peddicord (1976) noted that the laboratory experiments did not evaluate physiologically sublethal effects, which may be more important ecologically than direct mortality. Lunz et al. (1984) in a recent summary of data for eggs, larvae, and adults of fish and shellfish harvested in the coastal zone found several of the molluscs and crustaceans tested were sensitive to 100 mg/l or more of suspended sediments during multiday exposures, although others were tolerant of higher levels of 100 g/l or more for 1 to 3 day exposures, a thousand fold difference in concentration.

The results of laboratory studies of marine fish vary. Moore and Moore (1976) found that turbidities of 126 to 135 mg/l increased the time for the European flounder to see its prey. Although it is likely to be of minor importance if the plume is short-lived, this nonlethal effect would surely reduce the feeding rate and, hence, the vigor of the affected animals. Effects of manganese nodule mining plumes on captive yellowfin tuna and kawakawa have been studied by exposing the fish to deepsea clays and nodule fragments. No detectable effect was found in adults at concentrations from 9 to 59 mg/l. Feeding continued to occur in concentrations of 11 mg/l, and no change in behavior was noted in the presence of a turbidity cloud (Barry, 1978). However, preliminary results by Barry suggested that turbidities greater than 4 mg/l sometimes caused feeding inhibition and coughing in tuna in the laboratory (Matsumoto, 1984).

Some studies of larval fish have also shown feeding behavioral modifications because of decreased illumination, a possible consequence of increased turbidity (Blaxter, 1980; Kawamura and Hara, 1980; Riley, 1966; Wyatt, 1972; Houde, 1975; Saksena and Houde, 1972; Houde, 1977). However, Matsumoto (1984) concluded from a review of existing literature that the dilution of the plume from manganese nodule mineship discharges would be rapid enough to prevent any significant adverse impact on tuna and billfish eggs, larvae, and adults.

A limited number of field observations have been made on the behavior of marine fish in areas of high turbidity. The results suggest adults are less sensitive than the young and that there are differences among species. Whitebait (immature herring) and sprats have been found to avoid areas where china clay wastes are being discharged. Mackerel, however, do not seem to avoid these areas and exhibited no problems in feeding, despite being visual feeders (Wilson and Connor, 1976; Shelton and Rolfe, 1971; Shelton, 1973). Fish are observed to be abundant off the mouth of the Columbia River where sediment concentrations may reach 10 to 100 mg/l (Pruter and Alverson, 1972). Ritchie (1970) noted no adverse effects from overboard dredge spoil disposal on 44 species of fish from Chesapeake Bay. Observations off Hawaii showed that densities of fish larvae were found to be negatively correlated with higher turbidities, whether natural or man related, which Miller (1974) suggests may be caused by avoidance of turbid areas. Lunz et al. (1984) summarized laboratory reports of significant mortality of white perch, yellow perch, and striped bass larvae at suspended sediments concentrations of 500-5400 mg/l after 1-4 days of exposure. Larvae in the open ocean would not be exposed to such concentrations for such long periods, as they would drift with the diluting turbidity current, and the potential significance of exposures in the field may be overstated by these laboratory data.

An excellent review of potential adverse effects on zooplankton from a deep seabed manganese nodule mining plume was conducted by Hanson et al. (1982). Many of these species are filter feeders which ingest particles on the basis of size. Research has shown that zooplankton would most likely ingest nonnutritive particles from a mining plume (Hirota, 1981; Hu, 1981), effectively reducing their food intake. Not surprisingly, large increases in the ratio of nonnutritive to nutritive particles are harmful. For example, concentrations of 0.6 to 6 mg/l of clay wastes from aluminum extraction resulted in lower body weights of copepods (Paffenhoffer, 1972). However, the effects of nonnutritive ingestion caused by presence of mining may not be readily distinguished from natural variability. Hanson et al., (1982) concluded from their review of manganese nodule mining wastes that the oceanic zooplankton community would probably not be significantly harmed. Even though these wastes included trace metals released from the nodule fragments and pelagic clays as well as suspended load, they noted the plumes would be rapidly diluted, exposures would be brief, and the animals could tolerate slight increases in trace metals concentrations.

Effects on marine phytoplankton are observed in response to decreased illumination in the laboratory, but these shading effects are not expected to be a problem in open waters. Again the high dilution that would immediately occur prevents significant effects. Measurements of primary productivity and light intensity in a mining plume from deep seabed test mining showed a possible 50 percent reduction of productivity in an area 18 km by 2 km over several hours (NOAA, 1981). In a commercial mining operation, a 50 percent reduction in primary production may occur over an area approximately 20 km by 20 km (Chan and Anderson, 1981). Plankton in the mixed layer might be expected to encounter reduced light over an 80-to 100-hour period. This effect is similar to the effect of a cloudy day (NOAA, 1981).

In summary, while most of the studies of dredge spoil and mine tailings disposal have limited relevance to the OCS (Bigham et al., 1982), they indicate adverse effects to the biota from increased turbidity are likely to be insignificant, as long as there is a high dilution of the material (Kaplan et al., 1974). Most organisms of the OCS are adapted to natural variations in turbidity and can tolerate the higher turbidities that may result from mining unconsolidated sediments if exposure is brief. (As noted above, swimming organisms can avoid a plume, while nonswimming organisms will drift with the plume as it rapidly dilutes). Mining consolidated rock should be less of a problem as a turbidity source since the particles released into the water column are expected to be larger and consequently settle more rapidly.

5.2.2 Sedimentation

Feeding mode, life habit, degree of mobility, or sensitivity of life stage all affect the vulnerability of organisms to sedimentation. Some organisms are able to burrow out from tens of centimeters of sediment, although there seems to be a maximum depth below which no escape response is initiated (Nichols et al., 1978; Hirsch et al., 1978; Maurer et al., 1978). Other species can tolerate a slight increase in sediment deposition above natural loads. Oysters have been found to be fairly tolerant of some increase in sedimentation, although a large amount of deposited material causes suffocation (Mackin, 1961; Dunnington, 1968). Adults react to slight increases through increased pumping, or in some cases, through closing their valves. However, Loosanoff (1962) found some animals died when stress was prolonged for more than 48 hours. Larvae and eggs were most sensitive, with normal development being affected at 188 mg/l and stopped at 2 g/l. Clam larvae and eggs in general exhibited less sensitivity to increased concentrations of silt (Davis and Hidu, 1969).

The resiliency of animals may be much less if their typical natural environment has low turbidity, such as is found in much of the tropics. Hermatypic corals are known to depend on light for growth (Goreau, 1961), with growth being inversely related to the amount of resuspended sediment (Dodge et al., 1974). Consequently, a substantial increase in suspended sediment in areas of coral growth could be of concern, even though many corals can withstand some sedimentation through active removal. Bak (1978) studied the growth rates of fringing corals before and after dredging in the Caribbean. Although light levels were reduced to approximately 1 percent of the surface illumination for only a few days, growth of <u>Madracis mirabilis</u> and <u>Agaricia agaricites</u>, both efficient sediment rejectors, was reduced by one-third for more than 1 month. Colonies of <u>Porites astreoides</u>, however, were killed as they were unable to remove the sediment, became covered with sediment, lost their zooanthellae (symbiotic algae), and died.

Other areas that may not be able to withstand slight increases in sediment deposition are those used by bottom-spawning fish. For example, in the North Sea where gravel dredging resulted in large pits 3 to 5 m deep, water flow over these areas was slowed, resulting in finer sediments being deposited (Dickson and Lee, 1973a and 1973b). Many of these pits fill in slowly, with measured rates suggesting that decades may be required before they fill with silt. They may never return to premining conditions. Similarly, monitoring of dredge channels along the Atlantic coast of the United States has likewise shown that silt-clay particles fill in the channels, in contrast to the surrounding sand environment, resulting in an altered substrate (Taylor and Saloman, 1967). In Europe, recommendations have been made to avoid those areas where herring attach their eggs to the seafloor as well as those areas and times of sand eel spawning (ICES, 1975; De Groot, 1979a). Similar bottom spawning species exist off both coasts of the United States (e.g., herring, winter flounder, sand eels, rock sole) and deserve attention, as the spawning areas of these species may be affected by increased sedimentation, especially if a fluid mud layer is created (Hirsch et al., 1978). Also, there are special environments, such as the Arctic (DOI, 1983b), where recolonization may be extremely slow, but on which little information is available. Wright (1977) observed that full benthic recovery may take more than 12 years as a consequence of gravel island building for oil and gas development in the Canadian Beaufort Sea.

Dunton et al. (1982) stripped the organisms from a small area in a cobble-kelp community in the Arctic and found most of the areas still bare after 3 years. Such slow recovery of a community suggests that this environment may deserve special attention. Deep-sea environments probably would be equally slow to recover, since they are also very cold and food is limited. Seafloor spreading areas with hydrothermal vents are another unusual environment that would deserve attention if any mining were anticipated near them.

In cases where most of the benthic community is adversely affected, recolonization will have to occur from populations outside the disturbed area. The rapidity of this process seems to be highly influenced by the similarity of the new substrate to the premining condition (De Groot, 1979b). De Groot (1979a) established that recovery of the benthic fauna would take 2 to 3 years following sand and gravel mining. Recovery is aided if some of the sand and gravel deposit is left so that the substrate remains similar. Pfitzenmeyer (1970) found that the upper Chesapeake Bay recovered to its original condition 18 months after dredge-spoil disposal when there was no major topographic or stratigraphic change and the sediment was similar. Kaplan et al., (1974) found that the number of species in an enclosed bay in Long Island before and after dredging differed as a function of sediment type, with sediment changes being related to the circulation changes that resulted from the dredging.

Other studies of dredged, inshore areas have found rapid recovery (Cronin et al., 1971; Harrison, 1967; Connor and Simon, 1979). However, in many cases, while the biomass may reach predredging conditions, the diversity and distribution of species do not always replicate the premining environment (May 1973; De Groot, 1979b). Such a shift in community structure has been reported in experiments with recolonization boxes at depths greater than 1 km (Desbruyers et al., 1980; Grassle, 1977; Levin and Smith, 1984). Opportunistic species able to move rapidly into an unoccupied area were the first organisms to settle in the boxes and had the largest populations. The number of those species, however, was low in comparison to adjacent areas. After 26 months, the species composition of the boxes in the deep waters still differed greatly from adjacent areas.

Shallow water studies have shown that marine communities must evolve through successional stages (Thistle, 1981; Shelton and Rolfe, 1971; Gallagher et al., 1983; Kaplan, et al., 1974) before the redevelopment of the predredging community begins. Gallagher et al., (1983) identified certain species that had to move into an area before other species could recolonize. These results suggest that having a similar substrate increases recovery, but other steps must occur before the premining condition is reached.

Species that produce a large number of pelagic larvae are frequently the first species that move into an area that has been defaunated. However, other qualities have also been found in opportunistic species. In intertidal environments, the first polychaete recolonizers were frequently species whose adult stages were mobile (Levin, 1984; Dauer and Simon, 1976). Levin also found that the scale of disturbance, the type of larval development (that is, pelagic or nonpelagic), the settlement patterns, and mobility of the species were important to the success of recolonization. Brooding adults of species that had a nonpelagic larvae rapidly recolonized small areas of disturbance.

Polychaetes that had pelagic larvae were more adept at moving into large disturbed areas, especially when the disturbance occurred during the peak of the larval-dispersal period. Consequently, the recovery rate of a mined area that results in small shallow pits may differ considerably from large areas that have been scraped in a contiguous manner.

In summary, sedimentation may have a significant effect on the life cyles of some bottom living organisims such as oysters and clams, particularly during larval stages. Such effects could be lethal or sublethal. Care should be taken therefore in the timing of activities likely to cause sedimentation.

Recolonization of dredged areas depends on a number of different factors, and in most cases a complete return to the premining condition is likely to be slow. If there are no commercial species involved, change may not in itself be harmful, but the importance of any change in population would need to be assessed for the specific operation.

5.2.3 Explosives impacts

Explosives were widely used at one time for deep seismic exploration offshore but have now been superseded by other methods such as air guns and sparkers. The present limited use of explosives underwater for mining is strongly regulated by both State and Federal authorities to minimize environmental damage, particularly in areas where commercial fishing is practical or protected species are present. In all cases of use in Federal waters, environmental analyses are required and all operations are subject to immediate shutdown if unacceptable environmental effects on marine communities are detected.

The use of explosives to break up overburden and fragment the mineral deposit will generate shock waves, which generally

The rarefaction wave is produced when the compression wave is reflected from the water-air boundary and is transformed with a loss of energy into a negative pressure pulse. These suddenly applied negative pressures appear to kill fish by explosion of the swimbladder. As a result the rarefaction wave causes more damage near the surface of the water than at depth where ambient pressures are higher. Dynamite produces much higher negative pressures than black powder and is again more harmful to fish. Baldwin (1953), for example, during his observations of the use of black powder in geophysical surveys in salmon fishing areas off California found no dead or injured salmon even though many were seen swimming in the blasting area before detonation. Rapid compression followed by the negative pressure pulse caused by rarefaction thus seems to be most responsible for injury to fish.

Several studies of fish kills showed conflicting results for the effects of detonation at different depths, but the conflicts seemed to result from the different environmental contexts. Kearns and Boyd (1965), studying explosions in the upper water column, concluded that the areas within which fish would be killed increased with increasing depth of detonation. Goertner (1981), studying explosions at the seafloor, found that the probability of death was reduced with increasing depth of explosion, and, hence, higher ambient pressures. The differences apparently relate to the location of the explosions, and perhaps, the absolute depths involved.

Research conducted in Japan on the relationship between explosion size, fish type, and distance from the blast found that damage always occurs to the fish's stomach when the
kg force is 5 Km^2 per square centimeter or greater. A force of 3 kg/cm^2 is considered safe. This force is equivalent to a distance of 200 to 500 m from a 1.5-ton explosion, the largest permitted by Japanese law (Padan, personal communication). X

Studies of both behavioral and physiological effects on fish larvae and juvenile stages caused by pressure pulses from air guns and explosive removal of structures were conducted in the Santa Barbara Channel under joint energy company and commercial fisheries oversight. The reports are in preparation, and similar studies are in progress in the Gulf of Mexico with MMS support. Results will be available prior to any anticipated OCS mining.

5.2.4 Light and noise

Light and noise generated by mining equipment may disturb and nearby benthic organisms and possibly modify behavior. However, many, if not most, mobile, nonterritorial organisms should be able to move away from the distrubance. Even though there is little natural light below 1 km, deepsea organisms have functional eyes and the light introduced during mining will attract some organisms and cause others to move away. Moreover, observations from submersibles indicate that fish exposed to bright, artificial light may be at least temporarily mesmerized, possibly blinded. The exact impact has not been determined (NOAA, 1981). X

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will cause some deaths in the benthic invertebrate and fish populations. The extent of the effects depend on the velocity of detonation. For example, research has shown that dynamite and TNT produce far more deaths in fish than black powder (Hubbs and Rechnitzer, 1952; Kearns and Boyd, 1965; Anonymous, 1947 and 1948). Thus, the effects cannot be predicted until the explosive material proposed for use in any specific case is determined. These explosives may be novel materials, since conventional mining explosives, such as gelignite and ammonium nitrate, may not be suitable in deep water where the pressure might reduce the effectiveness of the explosion, (DOI, 1983a).

Adverse effects from individual explosions should be brief and confined to a small area since explosive forces rapidly dissipate with distance from the source. Significant, permanent, adverse impacts on the biological community would be unlikely unless either rare or unusual species occur near the mining operation or the cumulative effects of repeated explosions differ greatly from the effects of single events. However, the presence of the normally prevalent species in areas subject to explosions during war, naval training, and occasional public works activities evidence lack of irreparable damage from repeated explosions. Rates of recovery probably will be similar to the rates of recovery from other forms of OCS mining.

The organisms most susceptible to the shock waves generated by the detonation of explosives are those fish species that possess a gas-filled swimbladder. The swimbladder is a membranous sac of gases that serves a hydrostatic function in most fish that possess it. In some fish it may even participate in the production of sounds (Gross, 1972). Fish without swimbladders are mostly deep water species or predators, such as sharks, which swim at various levels in pursuit of prey. Young (1973) found that invertebrates living on or near the seafloor are more tolerant of explosives than fish with swimbladders.

The individual components of an underwater explosion important to impacts on fish are thought to be the amplitude (peak pressure), the type of compression wave, and the rarefaction wave (Hubbs and Rechnitzer, 1952). In an explosion, two types of positive pressure waves are produced, the initial compression or shock wave and the following bubble-pulse wave (Cole, 1948). The compression wave causes the primary disturbance to the water. Dynamite detonates instantaneously and produces a sharp shock wave with an abrupt front of intense pressure, which can seriously injure fish with swimbladders. Black powder burns more slowly and produces a less intense peak pressure that is less injurious. The bubble-pulse wave from both dynamite and black powder explosions is of relatively long duration and low maximum pressure. No major impact on fish was observed from this wave by Hubbs and Rechnitzer (1952), although some difficulties have occurred with shallow explosions in seismic surveys. These reported problems, however, may have been caused by rarefaction waves.

5.2.4 Mining noises

Not much is known about the intensity, frequency, and duration of mining noises. The type of collector most likely to be used for mining manganese nodules may attract scavengers, especially species like the rat-tail fish, that communicate by sound (NOAA, 1981). Noise also affects marine mammals, but the signficance is not well known (DOI, 1983a; DOI, 1983b). Most research has been conducted on the effects on endangered and/or threatened marine mammals from OCS oil and gas activities. Some researchers (Geraci and St. Aubin, 1980) have suggested that most animals become habituated to low-level background noise, such as ship traffic and onshore offshore petroleum activities; however, some animals show abrupt responses to sudden disturbances. Responses to continuing abrupt noise disturbance by California sea lions, Stellar sea lions, and harbor seals are fairly well documented (DOI, 1983a). Gales (1982) found that, although there were no significant physiological effects, possible auditory effects from a sonic boom, a pulse somewhat similar to explosive seismic pulses, include startle, flight, auditory discomfort, and hearing loss. Stationary dredging operations in the arctic did not seem to greatly disturb beluga and bowhead whales, but their swimming patterns did change within 2.4 km of dredging operations (DOI, 1983b). MMS-sponsored studies of the effects of noise on grey whales off the California coast also found that ship and air gun noises affect behavior, but much less so than biologically meaningful sounds, such as the sounds of killer whales. This response seems likely to be true of other animals as well. It is probable that the effects of mining noise will resemble the effects of noises from harbors, mechanized fishing gear, military maneuvers, and shipping.

6. Conclusions

The following conclusions can be drawn from the research and operational experience cited in the preceding sections.

- Mining in the OCS will produce effects from both the mining itself and the transport, beneficiation, and refining of the ore mined.
- The nearshore and onshore effects associated with the transport, beneficiation, and refining of the ore are common in existing ports, and hence familiar.
- Site-specific studies or monitoring of environmental effects of OCS mineral mining will often be necessary during at least pilot tests of new equipment and new operations. Knowledge of the method of mining, the type of ore, and the characteristics of the mine site are needed to be able to predict the effects at the level of detail needed in EIS's.
- The OCS will be mined by the four basic methods of mining used for solid deposits on land: scraping the surface, excavating a pit or trench, drilling a borehole and removing the valuable constituent in a slurry or as a solution, or tunneling. Any of these mining methods is applicable to more than one type of mineral deposit.
- Near-field effects associated with fragmentation/collection on, or excavation of, the seafloor will be limited to the periods of active mining and will be limited to the mine site.
- Far-field effects in deep, oceanic waters are the least known, with resedimentation being the main concern. Of particular concern is the effect on benthic organisms and the repopulation of mined areas.
- Because of the rapid dilution prevalent in the waters of the OCS, organisms living in the water column are unlikely to be exposed to adverse concentrations of suspended sediments. In the immediate vicinity of mining operations exposure is expected to be brief due to the transient nature of the plume.
- Organisms living at the seafloor are the most likely to be affected because of the resedimentation of the benthic plume, the actual destruction of the biota, and the change in the character of the seabed.

The MMS has prepared this document in recognition of the need to provide the public with an early overview of possible OCS mining activities and potential impacts on the environment. The MMS intends to prepare additional documents to comply with the National Environmental Policy Act (NEPA) as leasing proposals develop and more is known about the nature, magnitude, location, and rate of future mining.

The MMS will provide a comprehensive framework for environmental protection during prospecting for, and mining of, minerals other than oil, gas, and sulfur through development of regulations, lease sale EIS's, and lease stipulations. Environmental impacts will be addressed through the environmental review process specified under NEPA. An EIS will be prepared before the first lease sale of any of these minerals in any new area where leasable targets are identified. These EIS's will include detailed coverage of the environmental issues and will be similar in scope to the EIS's prepared for onshore mining and the offshore oil and gas programs. The NEPA process will provide significant opportunities for public involvement and comment.

The MMS is providing and will continue to provide opportunities for early input from State and local governments and the public. The MMS is developing the leasing program for minerals on the OCS with the aid of joint Federal/State task forces, where the States are willing to participate in these joint efforts. The task forces, through open meetings and consultations, will assess the economic feasibility of mining, the potential environmental problems, and measures to mitigate environmental problems. A task force studying a specific leasing proposal will reports its findings to the Governor(s) and the Secretary of the Interior. However, this program is an evolving process and there may be cases where a task force would not be to the benefit of the State or the Federal Government, and other new, innovative, leasing approaches may also be used.

At this time MMS is developing a case-by-case leasing program with State cooperation in the belief that both the recovery of minerals and protection of the environment can be best accomplished by such an approach. The case-by-case approach allows analysis and regulatory control to match the varied operational and environmental factors and issues as these become better defined. After issuing a lease, the MMS will require that detailed exploration plans and site-specific mine plans be submitted. Before the MMS approves new mine plans, or modifications of existing plans involving significant changes in potential environmental impacts, environmental documentation specific to those plans will be prepared and considered, allowing additional input by the public and adjacent States. Only then may mining be allowed to proceed.

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Appendix 1

I. English to Metric

Customary (English) Units	Metric Units
° Linear Measures	
foot	0.3048 meters
fathom (6 feet)	1.8288 meters
statute mile (5280 feet)	1.6093 kilometers
geographic (nautical) mile (6076.115 feet)	1.8520 kilometers
° Square Measures	
acre	0.4047 hectares
square statute mile (640 acres)	259.0 hectares
square statute mile	2.590 square kilometers
° Volume Measures	
cubic foot	0.0283 cubic meters
cubic yard (27 cubic feet)	0.7646 cubic meters
° Weight Measures	
short ton (2,000 pounds)	0.9072 tonnes (metric tons)
short ton	907.2 kilograms
long ton (2,240 pounds)	1.016 tonnes (metric tons)
long ton	1016 kilograms

II. Metric to English

Metric Units	Customary (English) Units
° Linear Measures	
meter	3.281 feet
meter	0.547 fathoms
kilometer	3281 feet
kilometer	0.6214 statute miles
kilometer	0.5400 nautical miles
° Square Measures	
hectare	2.471 acres
square kilometer	247.1 acres
square kilometer	0.3861 square statute miles
° Volume Measures	
cubic meter	35.31 cubic feet
cubic meter	1.308 cubic yards
° Weight Measures	
tonne (metric ton)	1.102 short tons
tonne (metric ton)	0.9842 long tons

Area[1] Comparison: United States Outer Continental Shelf and Exclusive Economic Zone

		Acres
(1)	Onshore Land Area[2]	2,355,000,000
(2)	OCS Planning Area[3]	1,438,000,000
(3)	OCS Planning Area + Onshore Land Area .	3,793,000,000
(4)	Minimum continental shelf [EEZ]	2,848,000,000
(5)	Minimum continental shelf outside OCS Planning Area	1,599,000,000
(6)	OCS Planning Area outside minimum continental shelf	215,000,000
(7)	Declared[4] continental shelf.	3,063,000,000[5]

Footnotes:

1. Areas include the Commonwealth of Puerto Rico, the U.S. Virgin Islands, Guam, American Samoa, the Commonwealth of the Northern Mariana Islands and other U.S. territories and possessions.

2. Land Area from U.S. Bureau of Census.

3. The OCS Planning Area is for the proposed 1987-1991 5-year oil and gas leasing program; total area between landward and seaward limits is given, without deletion for deferrals or exclusions.

4. The declared continental shelf (i.e., combination of the OCS Planning Area and the minimum continental shelf) does not represent the total extent of the U.S. continental shelf; the seaward limit of the U.S. continental shelf, including the seaward limit of the OCS, is not yet established, and in some regions the legal continental shelf will extend beyond the 200-mile minimum continental shelf. Further, some international boundaries with other coastal nations affecting the U.S. continental shelf and EEZ have not yet been agreed to with the respective nations.

5. The sum of the minimum continental shelf and the OCS Planning Area outside the minimum continental shelf does not exactly equal the sum of the OCS Planning Area and the minmum continental shelf outside the OCS Planning Area as the landward limit of the OCS does not coincide with the landward limit of the minimum continental shelf offshore Texas and Florida in the Gulf of Mexico.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.